AWS/TN-81/001

FORECASTING SKILL

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January 1981

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AIR WEATHER SERVICE (MAC)
Scott AFB, Illinois 62225

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AWS/TN-81/001 ✓	2. GOVT ACCESSION NO. AD-A099778	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Forecasting Skill		5. TYPE OF REPORT & PERIOD COVERED Technical Note
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Colonel Kenneth E. German		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS HQ Air Weather Service/DN Scott AFB, IL 62225		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AWS/DNT		12. REPORT DATE January 1981
		13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Weather Forecasting Skill
Weather Forecasting Experience
Weather Forecasting Education

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The accuracy of centrally produced prognoses has improved throughout the past 20 years; however, several studies have shown negligible improvement in weather forecasting. Available data, more than 100 journal articles, were reviewed to independently evaluate weather forecasting improvement. Overall forecasting skill improved for most weather elements; however, improvement was not obtained by all. This led to a review of other factors (education, experience, interest, and procedures) that might be

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Block # 20.

important in determining forecasting skill. After basic education and experience have been achieved (2-3 months), the main factor contributing to forecasting skill was found to be forecaster motivation. The AWS emphasis on accurate weather forecasting apparently has been effective, and should be continued.

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EXECUTIVE SUMMARY

Over the years many meteorologists have declared that improvement in weather forecasting has been negligible in spite of significant improvements in meteorological observations, data communications, and analysis and prognosis procedures. In the most recent 10 to 15 years, concern increased as it became clear that the accuracy of centrally produced prognoses steadily improved, while accuracy of weather forecasting, as determined by several studies, showed negligible improvement. At the same time, other studies showed improvement. Since improved weather forecasting is a stated goal of numerous projects involving relatively large monetary outlays, a study was begun to examine available data to independently determine whether weather forecasting was improving. We found that it was.

More than 100 articles applicable to the subject were reviewed. Of these only a few contained data. These studies were individually summarized and assessed in the second section. The overall finding was that there was significant improvement in forecasting skill for nearly every weather element. In nearly every case, the trends were statistically significant. It is clear that weather forecasting overall has improved in recent years at a rate that is generally in agreement with the improvements obtained by the numerical weather prediction models. Some studies definitely indicated no improvement for weather elements for which other studies showed significant improvement. Accordingly, it became important to consider other factors that might be important in determining forecasting skill. This was done in Section III.

Several factors commonly cited as being significant in determining forecasting skill are meteorological education, forecasting experience, forecaster interest and aptitude, and weather station operations (systematic procedures and forecaster workload). Generally few studies are available that address these subjects. Those available indicate that beyond an initial 2 to 3 months meteorological education and 1 to 2 months experience, there is negligible improvement in forecasting skill. Some authors asserted that forecasters having greater education and experience forecast the rarer events more accurately; however, this result could not be unequivocally established. Furthermore, much of this experience could be learned through study of forecaster references. Forecaster interest and aptitude were accepted as important. In general, however, forecasters are not selected through achievement of high ratings in these areas. We then considered some aspects of weather station operations. Overall, systematization of weather station forecasting has not been successful. Problems cited by Willett (1951) remain extant. Forecaster workload was discussed; it was noted that the time generally available for forecasting had not increased even though numerous time consuming analysis and prognosis procedures were now being provided to the weather stations by centrals.

Forecaster motivation was identified as a factor which appears to be a component of forecasting skill. This conclusion was based on the assumption that the rapid growth of commercial weather services was an indication that financial motivation was effective, and on personal experience in working with Air Weather Service forecasters for a number of years. Air Weather Service has been emphasizing forecasting performance, and the performance results have shown large increases in skill. Military experience has been that the single most important factor in successful weather station operations was the person in charge. Experiments that could be conducted might include subjects such as measuring the performance of highly experienced, highly educated, minimally experienced, and minimally educated forecasters; and the effect on forecasting skill of less workload and bonus pay for performance.

In general, the overall result of this effort was a revalidation of the cost effectiveness of Air Weather Service emphasis on a forecaster force mostly composed of enlisted personnel. It indicates that corporately we may be overly concerned with forecasting experience and formal training, and insufficiently concerned with forecasting motivation, forecaster selection, and enhancing the thought processes required for forecasting. The AWS emphasis on forecasting skill apparently was effective, and should be continued. Numerical weather prediction efforts should continue, and are likely to improve weather forecasting over the next few years. Further improvements likely will be achieved through continued emphasis on weather forecasting skill and on effective programs to encourage forecasters to routinely do the hard mental work with basic meteorology that is essential for good weather forecasting.

ACKNOWLEDGEMENT

The effort reported herein was accomplished as Air Force duty; however, the views expressed are those of the author. Air Force support implies neither agreement nor disagreement.

I am indebted to Lt Cols Iwan Choronenko and William F. Johnson for comprehensive reviews and numerous suggested improvements of content and style. Mrs. Mildred Revoire did all typing and layout work.

INTRODUCTION

Throughout this century, meteorologists have been striving to improve the accuracy of weather forecasting. The consensus has been that significant improvement could be obtained by increasing the density and frequency of weather observations, improving the flow of data for more rapid analysis, and developing more powerful forecasting techniques (Byers, 1944; Willett, 1951; Kreitzberg, 1976; Pielke, 1977; AMS, 1979; and many others). Large resources have been expended toward the attainment of these goals. Although remarkable advances have been made in all these areas and in synoptic meteorology, many feel the improvements in forecasting the weather (clouds, winds, precipitation, and obstructions to vision) have been small (Holzman, 1947; Dunn, 1951; Willett, 1951; Sanders, 1973, 1979, Bosart, 1975; Jensen, 1975; Ramage, 1976, 1978; Cook and Smith, 1977; Fawcett, 1977; Brown, 1978; Shuman, 1978; Smith, 1979; and Rinne and Frisk, 1979). A study was undertaken to evaluate the trends in forecasting performance, and to assess factors affecting forecasting skill. The approach was to review forecasting skill information published from the late 1940s to the present. Forecasting skill achieved through both objective (numerical) techniques and forecasters' subjective improvements were considered. A summary of the 1950 weather forecasting state-of-the-art is given as background.

Weather Forecasting State-of-the-Art in 1950

Weather forecasting generally is considered a three step process: analyzing, prognosticating, and determining the forecast weather. In 1950, analyses were considered generally adequate, although additional observing sites were needed, primarily in remote and ocean areas. Prognoses for periods up to 36 hours were considered essentially satisfactory. Determining the forecast weather from these prognoses was done by subjectively considering the effects of various dynamical and physical processes which might have acted or be acting on the air mass. Willett (1951) stated that negligible progress had been made in the previous forty years in determining the forecast weather in spite of greatly improved instruments and increased numbers of weather observing locations. Reasons he gave included a large increase in numbers of weather forecasters without the necessary aptitude, training, and experience; lack of standard forecasting procedures; and lack of authoritative direction. Willett suggested that improvement in determining the forecast weather was possible by improving the reliability and distribution of weather observations, standardizing techniques, and improving the process of selecting and training weather forecasters.

Reichelderfer (1951) noted that despite remarkable advances in understanding meteorology, comparable improvements in accuracy of weather forecasts had not occurred. He suggested that forecasters in general had not been able to assimilate the recent large increases in knowledge, noting that ever more demanding forecast schedules left little time or incentive to keep up with voluminous new meteorological literature. Others also had noted substantial improvements made in understanding meteorology, and in improving instruments, observation frequency, aerological observation quality and frequency, numbers of reporting stations, advances in prognostic techniques, and the data collection system. These improvements were often perceived as not accompanied by comparable increases in accuracy of determining the forecast weather.

Forecasting weather was generally perceived as requiring highly educated, trained, and experienced personnel with special aptitudes. Research was directed toward improved understanding of atmospheric processes, with little study being done of how to improve forecasting skill, assuming increased skill would accompany increased knowledge. At this time, economics and science both led toward increased centralization of weather forecasting activities resulting in major changes in station forecasting procedures. This and the impact of computers and satellites will be discussed next.

Centralization

In the early 1940s, rapid expansion of requirements for meteorological services forced consideration of new ways to meet needed service. It was soon recognized that it would be prohibitively costly to staff all weather stations with enough people to plot and analyze all charts needed for quality forecasting. Consequently, analysis centers were established and manned by the best qualified scientists. The analyses were disseminated by facsimile, making numerous high quality analyses available for production of needed forecasts (Holzmann, 1947). The advantages of analysis centralization soon led to prognosis centralization.

There were several reasons for centralization. During World War II, the number of stations reporting increased greatly, observations became routinely available to greater altitudes, and a great deal was learned about weather map analysis and prognosis. The commonly accepted procedures for analysis and prognosis had expanded so much that they could not be accomplished in the weather stations with available manning and meteorological expertise. At the same time requirements for weather services, such as more frequent observations (meteorological watch) and increased tailoring of weather products and services were increasing.

The procedures used for preparing prognostic maps out to 36 hours essentially were based on extrapolation, subjectively modified based on the forecaster's experience and understanding of applicable theory (Godske, et al., 1957). In general the entire process was highly subjective, including analysis. Sometimes different central analysis and forecasting teams produced radically differing analyses and prognoses using the same data (Thompson, 1961). However, the overall accuracy was considered satisfactory. Prognosis verification exhibited a relatively level trend from year to year. Fronts, precipitation areas, and so forth were analyzed to an accuracy of about 50 kilometers; prognoses for 24 to 36 hours were accurate within 100 to 200 kilometers (Bundgaard, 1951). Centralization continued, and in 1955 the National Weather Analysis Central was formed at Suitland through merger of the Weather Bureau, Air Force, and Navy Centrals in the Washington, D. C. area. This change in the weather forecast production system has not been associated with any identifiable improvement in forecasting accuracy. (See Fawcett, 1962 and Shuman, 1978).

Numerical Weather Prediction

As early as 1950, research in numerical weather prediction was active. Many of the basic problems had been solved, and bigger and faster computers were being developed. By 1955, many had become convinced that, "The development of numerical methods of weather analysis and forecasting is one of the most significant and spectacular advances in the practice of weather forecasting and the science of meteorology ...." (Thompson, 1961). In 1955, the Joint Numerical Weather Prediction Unit began daily production of computer generated forecasts for North America (Fuller, 1977). Figure 1 shows the verification data for both manual (m) and computer prepared 30/36 hour surface and the 36 hour 500 millibar prognoses. The dramatic improvement in score during 1958 has been attributed to the barotropic numerical forecasts becoming available in time to be used as the basis for the NMC official (manual) 500 millibar prognoses. The surface prognoses show a modest (12%) improvement after 1955, and a small (3%) improvement beginning after 1965, reflecting more complete and systematic use of numerical products. (Fawcett, 1962). The manual production of the 500 millibar prognosis was stopped when it became apparent that the computer produced forecast was about as good as the manual product. Figure 1 shows a substantial improvement in the performance of the guidance products. It is generally agreed that in contrast to the computer, forecasters cannot produce comparable prognostic charts for large (hemispheric) areas; however, they can improve the prognoses for limited areas through use of later data (Snellman, 1977; MacDonald, 1977; Bosart, 1978; Brown, 1978; Cahir, 1978; and Cook and Smith, 1978).

The performance of the Limited-Area Fine Mesh (LFM) prognoses over the CONUS shows further improvement. The practical range of SI* scores for the 500 millibar charts is from about 20 (nearly perfect) to about 70 (which corresponds to climatology) (Shuman, 1978). Thus, in the twenty odd years since numerical weather prediction models have been operational, over 70 percent of the possible improvement has been achieved for 36 hour CONUS 500 millibar forecasts. This achievement cannot be directly interpreted as an improvement in weather forecasting. Even with the superior accuracy of the LFM, forecasters can improve the prognoses over limited

*The SI score (Teweles and Wobus, 1954) is a measure of forecast pressure/ height change error relative to the larger of the forecast or observed pressure/ height gradient.

areas as mentioned above. The surface charts are not as accurate as the 500 mb prognoses, and the moisture and vertical velocity prognoses need considerable improvement even though substantial gains have been made since the first forecasts. The moisture and vertical motion fields are now routinely modified by National Meteorological Center precipitation and cloud forecasters (Brown and Olson, 1978).

Meteorological Satellites

The advent of the meteorological satellite was hailed as a major scientific breakthrough that would lead to significant improvements in forecasting. While this may have occurred in some instances, we have found no published supporting data. There are, however, many new techniques for obtaining better understanding of various meteorological processes. As examples, see Weldon (1979) for relationships between cloud patterns and upper air wind flow, Miller and McGinly (1978) for relationships with severe convective weather, and Gurka (1978) for fog forecasting. At the present time, meteorological satellite imagery is not automatically included in most weather prediction models; much additional work is needed. In some respects the availability of satellite data may have contributed to the loss of a number of observing stations for both surface and aloft, and created changes in personnel and operational concepts that tended to counteract some of the innovative advantages of the satellite.

Initially weather satellite information consisted of visual and infrared images with moderate resolution. These pictures helped meteorologists recognize cloud patterns better, but the knowledge was gained incrementally over a period of several years. Thus, no specific impact was noted in the published verification data. In time, polar orbiting satellites produced better images, permitting observation of smaller details. Images became available at 12 hour intervals, but these times did not correspond to times when other data were available. As a result, the forecasters had to do a lot of manual correlation (eyeballing), and this translation often was not accurate. Nevertheless, the satellites improved the forecasters' understanding of cloud distributions and analyses over data sparse regions.

Geostationary satellites provided an immense increase of data. Every half hour visual and/or infrared images were produced for about 60° latitude from the subsatellite point on the Earth's equator. Temporal correlation with synoptic observations was now possible, permitting the inclusion of satellite information on analysts' work charts. In spite of this, the data continued to be produced at different scales and manually transferred to analyses. The frequent images over the same geographic area added a new capability. Rapidly changing cloud patterns are associated with important and severe weather. Most of these events are now identified within the hour so that forecasters in facilities with satellite data are much more aware of developing weather changes than they were in the presatellite era. One indication of the operational usefulness of the GOES data is provided by a short unpublished study done by the 7th Weather Wing Aerospace Sciences personnel. The performance, as measured by the Air Weather Service skill score (possible percentage improvement over persistence) at three stations was compared before and after getting routine access to GOES data. The improvement averaged 15 percent at 3 hours and 54 percent at 6 hours. These improvements occurred at a time when wing-wide forecaster experience and manning were low, and the skill score at other wing units increased less than 3 percent during the same period. Otherwise, no references were found which document improvements in performance attributed to satellite images. Perhaps there has been no discernable improvement overall.

Techniques have been developed to make temperature soundings of the atmosphere from the polar orbiting satellites. The first versions were not successful, but a second generation is now in operation. The soundings are not as structured as the radiosonde, however, the main features are sufficiently accurate. The satellite soundings are helpful in sparse data regions, and recent tests (Ohring, 1979) indicate an improvement of 1 to 2 points in the standard scoring system (SI) for prognoses in the 48 hour range. At present rates of improvement, this is equivalent to a 2 to 5 year advance of the state of the art or a 2½ to 5 hour extension of forecast capability in the 48 hour forecast range.

Summary

During the 1940s significant increases were made in the numbers of surface and upper air observations, and in the speed with which these data were transmitted. The additional data led to rapid improvements in weather analysis and to significant improvements in forecasting techniques. The additional data and new techniques caused weather station manpower requirements to increase substantially; this problem was solved through centralization of weather map analysis and prognosis. Personnel in the weather centrals were selected for their meteorological knowledge and skill in weather map analysis and prognosis, and the process of expertise decay in base weather station began. It is assumed that the forecasting performance improved during the 1940s, but verification data were not found. By the early 1950s, forecasting performance, as measured by verification of the 30 to 36 hour surface and 500 millibar prognoses, was essentially level. Subsequently, significant improvements were achieved, primarily through advances in numerical weather prediction. Analysis and prognosis of clouds improved with increased availability and use of weather satellites; however, the use of weather satellite data remains a developing technology. Although many specific techniques for analyzing weather satellite imagery have been identified, much remains to be done before full use of such systems can be achieved. Overall, then, substantial improvements were made during the 1940s and 1950s in those areas recommended by meteorologists as being likely to improve forecasting -- density and frequency of weather observations, faster data flow and analysis, and more powerful forecasting techniques. As a result, substantial improvements in weather map prognoses were achieved. The next section considers the corresponding changes in forecasting the weather.

FORECASTING PERFORMANCE

Forecasting performance, as measured by verification of 30 to 36 hour surface and 500 millibar prognoses, became essentially level in the early 1950s. Subsequently, significant improvements were achieved through advances in numerical weather prediction. In spite of large improvements in the accuracies of the prognostic maps, some suggest that little improvement has been achieved in forecasting clouds and weather. Several studies will be discussed.

The Massachusetts Institute of Technology (MIT) Forecasting Game

The MIT departmental weather forecasting program was developed to provide instruction in the ways of the real atmosphere (Sanders, 1973). Forecasts were made weekdays for the probability that the minimum temperature would exceed the normal minimum for the date and probability of at least .01 inches of precipitation at Logan International Airport, Boston, MA. Probability forecasts of distributions of temperature and precipitation amounts were also made. Climatological mean values were used for guidance and as control forecasts. The forecasts were for four consecutive 24 hour periods, beginning at 1800 GMT of the current day. The first period was called the 24 hour forecast and the last the 96 hour forecast. Forecasts had to be completed not later than 1330 local time (during winter this completion time was 30 minutes after start of the first forecast period). Most forecast deliberation occurred between 1200 and 1330. Facsimile and teletype data were available for study at all hours. The program was open to anyone, but the participants were mainly graduate meteorology students and undergraduates taking meteorology courses. Each day a consensus forecast was made; it was the average of those participating for the given day, forecast element, and time period. Each forecaster was scored against the consensus forecasts, and only for the forecasts he made. The scores for the minimum temperature forecasts were absolute error; the Brier score for precipitation and, the Murphy's Ranked Probability Score for the forecast temperature and precipitation amount class probability distributions.

The trends for consensus forecasts of minimum temperature and probability of six classes of precipitation amount forecasts are shown in Figures 2 and 3 (Sanders, 1979). The performance showed negligible improvement for 12 years—a stark contrast to the significant improvement shown in Figure 1 for surface and 500 millibar programs; however, the level of performance was high, 40 to 50% improvement over climatology for the first period. The lack of an improved trend was interpreted by Sanders (1973) as resulting from large errors in the first period forecasts due to mesoscale effects (shallow fronts, land-sea contrast, convective showers, and inaccurate timing of non-convective precipitation). Consensus performance, by remaining more or less steady in the absolute sense, actually deteriorated relative to the rising state of the art. It was suggested that this was due to inexperience. Sanders' own performance was essentially constant relative to consensus, indicating a decrease of his skill relative to the state of the art, and discounting experience as the reason for the relative deterioration of the consensus forecasts. It is possible that the model skill was too small to be seen in the excellent forecasting performance achieved, but model skill improvements eventually should be reflected in the longer range forecasts.

The performance of the consensus forecast relative to objective guidance produced by NMC using the 1200Z data base was also evaluated. The skill of the guidance improved rapidly during the late 1960s, but was nearly constant after 1972. The percent improvement of the consensus forecast over guidance was about 18% overall for minimum temperature and 40% for quantitative precipitation forecasts. While the sample size used in these evaluations was not large enough to be conclusive, it certainly is thought provoking. Sanders (1973) suggested further studies using broader data base; a similar program was established at the State University of New York at Albany (SUNYA).

The SUNYA Forecasting Game

The forecasting game at the State University of New York at Albany was essentially the same as the one at MIT (Bosart, 1975). However, only two forecasts were made for each 24 hour period - the probability that the minimum temperature will be below the climatological minimum, and the probability that there will be measurable precipitation. The participants were mainly graduate students. Initially there was no forecasting experience other than the author's participation in the MIT game for five years. The results are shown in Figures 4 and 5. Again the level of skill was high, a 40 to 50 percent improvement over climatology for the first period. There is no trend for the consensus temperature forecasts and for the third and fourth day precipitation forecasts. A marked improvement was shown for the consensus 24 hour precipitation forecast, and small improvement was shown for the consensus 48 hour and all hour forecasts. Among the factors Bosart listed as contributing to these results were: (a) The experience level of the student forecasters had increased significantly by the spring 1972 semester, (b) The students reduced use of large departures from the climatology forecasts for the 72 and 96 hour forecasts, and (c) The introduction of the LFM and model output statistics (MOS). The LFM used 1200Z observations, but was projected for only 48 hours. The MOS data were derived from the previous evening's 00Z data base, and projected further in time. Bosart's personal results are shown in Figure 6 in terms of percentage improvement over consensus. Like Sanders', there is no clear trend overall for either precipitation or temperature. In general, this study supports the results reported by Sanders (1967, 1973) of no long term improving trend.

Forecasts at Louisville, Kentucky

Public probability of precipitation and maximum/minimum temperature forecasts for Louisville, KY were evaluated by Cook and Smith (1977). The forecasts were for 12 hour periods over a ten year span (1966 - 1975). Each period was evaluated separately and compared to guidance forecasts issued by the National Meteorological Center. There was little change in the quality of precipitation forecasts issued even though central guidance had improved; however, forecasters were able to recognize instances where the guidance forecasts were significantly in error (GT 30%). In such cases, improved forecasts were issued for about 70 percent of the cases for the first period, 60 percent for the second and third forecast periods. The overall quality of the temperature forecasts also exhibited little change over the ten year period. Temperature changes of 10°F or larger were forecast slightly better by the WSFO in the first and second periods. Generally, these results confirm Sanders' (1973) suggestion that, in spite of improvements in meteorology, weather forecasting had not improved through 1975.

National Weather Service Precipitation Forecasts

Charba and Klein (1980a and b) surveyed the accuracy of different types of precipitation forecasts produced in the National Weather Service. The study included objective and subjective guidance forecasts prepared at the National Meteorological Center (NMC), and the local forecasts issued by the forecast offices using the guidance forecasts.

Categorical Forecasts of Measurable Precipitation

The NMC forecaster who prepares the precipitation areas appearing on the national surface prognostic charts assigns yes/no measurable precipitation forecasts for 12 hour periods at 60 stations. The accuracy of these forecasts is measured in terms of threat score. Annually averaged threat scores for several projections are shown in Figure 7. The annual threat scores produced by the numerical forecast models are shown for comparison. The forecast projections for the models are from model initial time; projections for the subjective forecasts are from issue time. Over the period of record both sets of forecasts improved. On the basis of linear regression, the 10 year increases in skill score of the 36 hour surface and 500 millibar objective prognosis were 11.5% and 13.5% respectively. The 10 year percentage increases of threat score for the NMC guidance forecasts were 24% for the shorter projection and 15% for the longer. The subjective forecasts use the objective forecasts as guidance. Since the trends are similar (correlation about .7), it appears that since 1970 the increasing skill of the subjective forecasts is mostly due to improvements in the objective guidance.

Smoothed annual percent correct of local yes/no precipitation forecasts are shown in Figure 8. Data are available for three cities (Washington, Boston, and Chicago) since 1954 and for 50 forecast offices since 1966. The regression line for the longer record shows an average rate of increase of 2.1% per 10 year interval. The trend for the 50 WSFOs is not significant at the 95% level. The improvement was not steady; there was negligible improvement from the mid 1960s to the mid 1970s. The sharp rise after 1975 is encouraging, but more data are needed to establish authenticity. We see that even though the skill of the guidance forecasts increased during the early 1970s along with the improvements of the 36 hour surface and 500 millibar prognoses, the improvements in the local forecasts issued to the public were smaller. This result was not true, however, for the probability of measureable precipitation forecasts.

Probability Forecasts of Measurable Precipitation

Probability forecasts of precipitation are issued to the public by the WSFOs for the periods 3 - 15 hours, 15 - 27 hours, and 27 - 39 hours after issuance (today, tonight, and tomorrow). Graphs of the annual verification for about 50 WSFOs are shown in Figure 9. The dashed line represents automated guidance (MOS since 1970) issued four hours earlier. The general level of performance for the three periods respectively were 35, 24, and 15 percent improvement of Brier Score relative to climatology. The WSFO forecasts indicate an improving trend with most of the improvement occurring after 1971. The average 10 year percentage increase in skill score was about 6%, 36%, and 66% in the first, second, and third periods respectively. The trend is not statistically significant for the first period, but is highly significant for the second and third periods. The 10 year increases in skill score were 6.9% and 7.4% respectively for the second and third period forecasts, about half that of large scale circulation forecasts of about the same projection (Charba and Klein, 1980b).

Since 1975 the subjective forecasts have been highly correlated with the MOS forecasts. There is a slight indication of MOS gaining on the forecasters in the first period, and the forecasters gaining on MOS in the second and third periods. Further study of these data show very significant differences in the trends of cool and warm season probability of precipitation forecasts (Figure 10). Improvement was greater in the cool season when most precipitation is caused by the synoptic scale systems which the numerical models are skillful in forecasting.

Quantitative Forecasts of Precipitation Amount

Specialized meteorologists at the National Meteorological Center have been preparing quantitative precipitation forecasts for the nation since 1961. Verification data are available for amounts equal or greater than 0.5 inch and 1.0 inch for the periods 0 to 24 hours and 24 to 48 hours. The trend for the 0 to 24 hour forecasts was level up through 1971. From 1972 to 1979 the 10 year change in threat score was about .08 for both amounts and both periods -- about the same improvement as the NMC subjective categorical precipitation forecasts. The centralized forecasts for heavy snow show a small upward trend over the past 18 years (Charba and Klein, 1980b). Zuckerberg (1980) found a small long term skill increase in forecasts of heavy snow events for nine eastern cities.

Other National Weather Service Forecasts

The Techniques Development Laboratory conducted a verification program to help validate and to improve use of the operational Model Output Statistics (MOS) forecasts. These data are summarized by season for the past four to five years in a series of Office Notes. Although the period of record is short, some trends are indicated. We have used data from only one of these reports for illustration (Hebenstreit, et al, 1979). The data are presented in terms of early and final guidance issued about 3 and 6 hours after initial map time, and local and persistence forecasts issued about 9 to 10 hours after initial map time. All forecasts use the latest available observation, and the local forecast uses the guidance as well.

Surface Wind

Figure 11 shows verification data for surface wind direction in terms of mean absolute error. In general there has been steady improvement, paralleling improvement in the MOS guidance. The surface windspeed verification data (not shown) provided similar findings, but there was negligible improvement. Two category verification (LTE 22 kts and GT 22 kts) is shown in Figure 12. The local forecasts show no significant trend although the MOS forecasts show improvement after 1974, especially for the 42 hour forecasts.

Sky Cover

The skill score for sky cover forecasts is shown in Figure 13. There has been a 4 - 5% improvement by the local forecasters over the five winter seasons. However, the 18 hour objective forecast (MOS) is superior to the locals. The 42 hour MOS forecasts have been more than twenty five percent better than the local forecasts for the entire period, and show a good upward trend.

Ceiling

Ceiling forecast verification for four seasons is shown in Figure 14. The 12Z (HR) and 15Z (HR) local forecasts have less skill than persistence. These forecasts are 3 and 6 hour forecasts from time of latest observation for persistence and local forecasts; projections for the objective forecasts are about six hours longer. There was no significant trend. The MOS forecasts show mixed results. Longer range forecast verification is shown in Figure 15. Local skill is small and is less than persistence. The MOS forecasts are better than either, and indicate an improving trend. However, this trend parallels the improvement of persistence and might not be significant.

Visibility

Verification data for visibility forecasts are shown in Figures 16 and 17. The 12Z (HR) local forecasts are worse than persistence, and there is no trend. The local forecasts improved over persistence for the 21Z (HR) verification time, These forecasts are for the same projections as the ceiling forecasts.

Temperature Forecasts

Verification data for maximum and minimum temperatures are shown in Figure 18 and 19 respectively. The local forecasters achieved slight improvement for the 24 hour maximum temperature and moderate improvement for the 48 hour maximum temperature forecasts. The latter, however, closely parallels improvements of MOS. No significant trend is evident for the minimum temperature forecasts except that the MOS improved in 1975 to be comparable to the local forecasters. Note that the local forecasters have about six additional hours of data and access to the MOS early forecasts.

Severe Storm Forecasts

An analysis of forecast skill at the National Severe Storms Forecast Center was presented by Pearson and Weiss (1979). The skill level (critical success index) of the severe local storm outlook has been increasing slowly (Figure 20). The increase is attributed to the improvement of the LFM model. The trend for tornado watches (Figure 21) suggests a slight improvement. These results were attributed to the difficulties inherent in attempting to make mesoscale forecasts using synoptic scale observation networks and forecast models. Radar and satellite data are mainly useful for diagnostic activities.

The Western Region Program

The MOS forecasts of probability of precipitation became available to National Weather Service Western Region forecasters in 1972. In the following three years the MOS forecasts improved significantly, while the manual forecasts improved little (Figure 22). The Western Region evaluated these results, and determined that it should be possible for forecasters to improve the MOS forecasts. A motivational program was implemented 1 Dec 75 (MacDonald, 1977; Snellman, 1977) in which management stressed improvement over MOS. The Region Headquarters provided weekly verification feedback and station ranking. Technical information also was produced and crossfed. This program promoted forecaster interest in MOS, in using their individual forecasting skills, and in sharpening their concern for the quality of the forecast product. The results were that forecasters were motivated, became better meteorologists, and produced the best probability of precipitation forecasts ever issued in the Western Region.

Ceiling and visibility forecasts were also evaluated in this program. Figure 23 shows Snellman's verification contingency tables. The overall percent correct for ceiling and for visibility forecasts were practically the same for both the MOS and the Western Region forecasters. However, the forecasters percent correct for the lowest three categories (less than 1000 feet and 3 miles) was much higher (28% and 33%) than MOS (11% and 13%). Snellman also pointed out that the forecasters had a much better bias than MOS. However, the MOS bias has been improved in recent years.

Air Weather Service Ceiling/Visibility Forecasts

The Air Weather Service quarter month verifications for all hours and for 3, 6, 12, and 24 hours are shown in Figures 24 - 28 respectively in terms of percentage improvement over persistence. Linear regression lines are shown dashed. The 10 year improvements of skill score are roughly 12.5, 25.1, 16.0, 6.8, and 8.4 percent for all, 3, 6, 12, and 24 hours respectively. The large improvement is due partly to the initial low skill. This performance still leaves much to be desired. The forecasts are biased toward forecasts of the highest categories. In addition, the skill of forecasts for the lowest category is worse than persistence for forecasts of six hours or longer. Most of the improvement was in the higher categories; only small skill was obtained for ceilings and visibilities less than 1000 feet and/or two miles.

Forecasting in Great Britain (Mason, 1980)

Since 1963 the 0755L forecast valid for the following 16 hours and the 1755L forecast valid for the following 30 hours have been subjectively evaluated. The elements (wind speed and direction, weather, state of sky, and maximum temperature) are each awarded marks 2, 1, or 0 according to whether the forecast is correct, partly correct or incorrect. The scores are similar for the four elements, and an average of the marks is taken as a measure of the overall performance. These forecasts are based on guidance from the Bracknell Central Forecasting Office issued some 2 1/2 hours earlier, in turn depending heavily on the predictions of the numerical models which have shown marked improvement in recent years. Ten years ago less than half of these forecasts were essentially correct, and 1 in 7 were seriously misleading. Since 1972 two-thirds have been essentially correct, and only 1 in 15 has contained serious errors. Significant improvements were also noted for the 48 hour and 72 hour projections.

Discussion

In general, most of the forecasts produced by the numerical weather prediction models, including Model Output Statistics, have shown improvement over the periods for which data were available. The significance of each improvement is difficult to assess because of the variety of scoring techniques and the time periods. However, rough comparisons were possible for the elements verified in terms of a skill score. A skill score for the numerical models (SS = 2 (70 - SI))) was developed by Shuman (1978). On the basis of linear regression lines, the 10 year rate of increase of skill score of the primitive equation (PE) 36 hour sea level and 500 millibar forecasts were 11.5% and 13 5% respectively (Charba and Klein, 1980b). These regression lines were based on 12 years of data except that the 500 millibar values included an additional five years of baroclinic model performance. In general, forecasting skill decreases with increasing projection time; however, the rate of improvement in skill generally is largest for forecasts of 36 to 48 hour projection. As a conservative rough estimate, we use a 10 year rate of improvement of 10% as roughly comparable to the improvement rate obtained by the numerical models. The following types of forecasts seem to be meeting or exceeding this proposed standard.

a. SUNYA consensus 24 and 48 hour precipitation percent improvement over climatology (Figure 5).

b. NWS locally issued and MOS probability of precipitation forecasts for second and third period for 50 weather service forecast offices (WSFO) (Figure 9). Most of this improvement is for the cool season forecasts (Figure 10).

c. MOS categorical wind speed for both the 18 and 42 hour projections (Figure 12). Only six data points are available; so the significance is uncertain.

d. MOS sky cover 18 and 42 hour forecasts (Figure 13). Only 5 data points.

e. MOS 18 hour ceiling forecasts. Only four data points. Also persistence scored high (Figure 15).

f. MOS 18 hour visibility forecasts. Only four data points (Figure 17).

g. AWS 3, 6, 12, and 24 hour four category ceiling/visibility forecasts. Significant at the 95% level (Figures 25 through 28).

Note that the above list mostly consists of MOS forecasts; exceptions are SUNYA probability of precipitation (POP), NWS POP, and AWS ceiling/ visibility forecasts.

Other types of forecasts which appear to have a similar improving trend, but not directly comparable include:

a. NMC subjective and objective categorical forecasts of measurable precipitation, first and second periods (Figure 7).

b. Washington, Boston, and Chicago subjective categorical forecasts of measurable precipitation (Figure 8).

c. MOS and local surface wind direction forecasts. Six data points (Figure 11).

d. MOS and local maximum temperature forecasts (Figure 18).

e. NWS severe weather outlook forecasts. (Figure 20).

f. Centralized quantitative precipitation forecasts of 1/2 inch and 1 inch and heavy snow (Charba and Klein, 1980b).

The remaining types of forecast show little or small improvement. These include:

a. MIT consensus probability forecasts for minimum temperature and class of precipitation amount for four projections (Figures 2 and 3).

b. SUNYA consensus forecasts for temperature for four projections and precipitation for the 72 and 96 hour projections (Figures 4 and 5).

c. Categorical forecasts for measurable precipitation issued locally by 50 WSFOs (Figure 8).

d. Warm season probability of measurable precipitation (Figure 10).

e. MOS and local wind speed (Hebenstreit, et al; 1979).

f. Categorical local surface wind speed forecasts (Figure 12).

g. Local sky cover forecasts (Figure 13).

h. Local and MOS 12 - 15 hour ceiling forecasts (Figure 14), and local 21 hour ceiling forecasts (Figure 15).

i. Local and MOS 12 - 15 hour visibility forecasts (Figure 16) and local 21 hour visibility forecasts (Figure 17).

j. Local minimum temperature forecasts (Figure 19).

k. NWS tornado watch forecasts (Figure 21).

We conclude that significant improvement has been achieved in forecasting nearly every element by at least one group of forecasters. This is contrary to the often made assertion of lack of progress. We note that progress obtained by one group or method often does not seem to be successfully attained by another group making similar forecasts. The objective forecasts, especially MOS, seem to offer the best chances of effecting improvement to all consumers for the 12 to 96 hour projections for those elements in which the objective skill roughly equals manual skill. We need continued effort to improve MOS, to make forecasters aware of the quality of the guidance and to encourage them to use it. This process seems to be occurring across the Nation. Still, it is curious that not all methods led to similar performance improvements for similar forecast elements and projections. Since all forecasting groups in the CONUS use the NWS facsimile package as the primary guidance, we infer that factors other than the quality of the guidance product must be important in determining the performance achieved. Some of these factors are discussed in the next section.

FACTORS AFFECTING FORECASTING PERFORMANCE

Significant improvements in weather forecasting have been achieved in recent years; however, the improvements were not achieved for every element by every forecasting group. Since the skill of the numerical weather prediction model guidance products has steadily improved in accuracy, factors other than the quality of the guidance apparently are important in determining the quality of the forecasts provided to customers. Over the years, small improvement in weather forecasting has been a recurrent theme in meteorological literature; suggestions given for improving forecasting included meteorological education, forecasting experience, individual aptitude and interest, additional real time observations, bigger and faster computers, better numerical models, and improvement of weather station operations. These suggestions, except for those addressed in preceding sections (observations, computers, models), will be discussed as factors that potentially affect the rate of improvement of forecasting skill.

Meteorological Education

Many consider university education or its equivalent mandatory for meteorologists (Baum, 1975; Newton, 1980). The World Meteorological Organization recommended training program for forecasters (Class II and Class I meteorologists) is equivalent to university education (see description by Van Mieghem, 1963). In most countries, university meteorological education is required for meteorologists; the only exceptions are the U.S. military enlisted forecaster and the occasional practice of accepting experience in lieu of formal education. Jenkins (1953) evaluated 92 forecasters ranked in the Air Weather Service (AWS) forecasting skill verification program (AWS, 1943). No significant differences were found between better and poorer forecasters with respect to education, college major, or mathematics background. Kershner (1957) used the peer evaluation technique to identify a number of good and poor Air Weather Service forecasters. Subsequently Kershner and Jenner (1959) and Kershner (1962) analyzed the characteristics of 300 officers and 129 warrant officers/enlisted weather forecasters. They found that the good forecasters in each group had more education, especially in mathematics and physics, than the poorer forecasters. No comparisons were reported between officers and enlisted.

In a university game at City College of New York, Gedzelman (1978) found no significant difference in the forecasting ability of meteorologically educated and uneducated forecasters (sample of 12). These results are supported by Bosart (1975) and Sanders (1979). Each started with people who were meteorologically uneducated. The programs began with a short course taught concurrently with the conduct of the forecasting exercise. After the first couple months, individual skill became level. The excellent performance results achieved by AWS forecasters (Fifth Weather Wing, 1980; German and Hicks, 1980) indicate that the 18 week weather forecaster training conducted by the Chanute Technical Training Center also provides enough knowledge of basic meteorological processes to do good weather forecasting. This course also teaches a number of Air Force specific operational procedures that shorten subsequent weather station orientation; thus, it should not be shortened. Cahir (1978) described experiments with an interactive system in which he indicated that the system is used successfully only by those who are able to integrate it into a good scientific approach. This implies a need for more than the elementary education mentioned above; however, no supporting data were presented.

We have noted that over the last ten years the Air Weather Service forecasters have become increasingly less meteorologically educated, but the overall forecasting performance apparently has not deteriorated. One of the reasons is that meteorologically educated personnel monitor the performance and provide guidance on development of logical scientific approaches to forecasting. In addition, guidance is provided on the strengths and weaknesses of the objective and subjective forecasting aids. Use of guidance such as the satellite discussion bulletins and map discussion bulletins prepared by meteorologically educated personnel is encouraged. Solutions to forecast problems are documented through case studies. Formal publications, refresher training of basic concepts, and an active staff visit program also help.

University education apparently provides a breadth and depth of knowledge not needed for routine base weather station forecasting. Even though this knowledge is not required for hour-by-hour, day-by-day forecasting, it is useful in complex forecasting situations, solving forecasting problems, and consulting. For example: Some units were having a problem with forecasting freezing precipitation in air masses that were colder than freezing. Thorough study of meteorological literature by a meteorologist revealed that cold stratus clouds often produce freezing drizzle. Several conditions needed for drizzle to occur were identified. The physical basis for the problem was identified, and guidance was given for forecasting. In this instance the National Weather Service subsequently verified the result for all CONUS (Bocchierri, 1979). Such efforts require a university educated meteorologist.

Although the general consensus of professional meteorologists is that university education is required to make an individual a good weather forecaster, available data generally do not provide support. Kershner and Jenner found that good forecasters tended to have more university education and poor forecasters tended to have less, but Jenkins found no relationship between forecasting skill and education. The skill demonstrated by the AWS forecasters, now mostly having no university education clearly demonstrates that university education is not required. Chanute training is adequate for good quality terminal weather forecasting. We have noted, however, that for continued good performance the forecasting system must have university educated personnel within it to help with problems, planning, training, and application of new technology.

Forecasting Experience

Forecasting experience (total and on station) intutitively is highly desirable for weather forecasters. Early in this century, experience was a primary tool used by forecasters; it continues to be considered important in 1980. It is logical to conclude that experience is a major factor since most good forecasters have experience; however, we acknowledge that there probably are more experienced forecasters of moderate skill than of good skill. Jenkins (1953), Kershner (1957), Gedzelman (1978), Bosart (1975), and Sanders (1979) indicated that forecasting experience has little relationship to forecasting performance. In the latter three studies, neophyte forecasters became competitive with the more experienced forecasters within one to two months of elementary meteorological education and practice. The Air Weather Service forecasting performance (German and Hicks, 1980), which showed significant and increasing improvement over persistence, from 1968 through 1979, was achieved by a force in which many of the forecasters had less than three years experience, especially toward the end of the period. Lininger (1979) reported on a two year project in which forecasters in his office participated in making 3 and 24 hour ceiling and visibility forecasts using very limited data (one surface and 500 mb map on Mondays, and the local official observation each day). These forecasters were university educated meteorologists, but not experienced in the area. The forecasts produced were skillful relative to climatology; forecasters achieved skill in one to two months, with little improvement thereafter.

The minimum thresholds of forecasting experience seem to be of the order of a couple of months, not years, for point (terminal) forecasts. This conclusion is supported by data analyses made by several individuals; however, there undoubtedly are exceptions. Forecasting experience apparently gives an individual a better sense of the spectrum of weather that could occur for a given synoptic pattern, but this sense, or knowledge, doesn't necessarily become better forecasting. Perhaps these individuals are not gifted in accurately selecting the most probable weather, or these instances occur too infrequently to show up in the mass of verification data. Gedzelman (1978) presented one example in which an experienced forecaster correctly forecast a backdoor cold frontal passage not forecast by guidance. Even though the possibility was discussed by all forecasters the inexperienced forecasters followed the machine objective guidance. Kershner and Jenner (1959) found that the age at which Air Force forecasters began forecasting was important; those who began before age 25 were better.

A few other specific instances of positive benefit of experience are available. Phillips (1979) cited an instance in which use of a case study resulted in an accurate forecast of a rare event. George (1960) presented numerous forecasting aids developed partly through forecaster's experience. German (1979b) cited a case study of a forecast at Mountain Home AFB, Idaho that was successful in large part because of the forecaster's experience with similar situations. Safford and Gesser (1977) described a procedure for forecasting passage of lake effect snow showers over airfields. Note that these examples all are of documented experience. Undoubtedly, there are numerous other examples. By the time a station has existed for about five years, most of the important synoptic and local effects should have been identified and documented in a station technical reference document or in case studies. If such documentation is not done, then each individual's insights unnecessarily depart upon reassignment of the individual. Experience apparently is helpful when it includes thorough post analysis and learning. In such cases, learning, not experience, probably is the effective factor, and could just as easily be done before as after the fact. This does not mean more education, only thorough review of available station references, climatology, case studies, etc., seasonally or more often as required. If this concept is accepted, it would be logical to include time for this learning in the station manpower computation.

Overall we must conclude that forecasting experience is only a minor factor in terminal weather forecasting performance at weather stations. It may have been important in the past, and it may still be important where the necessary information is not available to learn. Documentation of forecasting experience in an organized, systematic way for forecasters to learn is more important. This should be considered and, if possible, provided for when weather stations are modernized.

Aptitude and Interest in Weather Forecasting

Willett (1951) stated that, "The empirical and esoteric nature of most weather forecasting today places a high premium on the natural aptitude of the individual forecaster. This natural aptitude is invariably indicated by a strong liking for and sustained interest in weather forecasting for its own sake over a long period of time...." Willett went on to say that aptitude and interest were not necessarily correlated with meteorological education. Aptitude and interest are not prerequisites for employment as a weather forecaster today. Military forecasters for example, are assigned forecasting duties on the basis of completion of an education program. Aptitude and interest apparently are developed serendipitiously at various stages of a forecaster's career. However, some management actions appear to have the effect of decreasing enthusiasm for exercising aptitude and interest. Actions needed or taken to correct this trend have been discussed by Snellman (1977), Kaehn (1978), and Schwartz (1980).

The studies reported by Kershner (1957), Sanders (1973 and 1979), Bosart (1975), and Gedzelman (1978) indicate aptitude and interest are important factors which contribute toward good forecasting performance. Ramage (1976), in assessing Sanders (1973) findings commented, "Perhaps this can be explained in terms of the innate ability of some individuals to think in a strongly nonlinear way and so to anticipate development ... from insignificant beginnings more accurately than their colleagues." AWS management has observed that people with an intense interest in weather forecasting usually provide good forecasting service. In the military this often is recognized by the customer; in some cases senior officers seek advice from the forecaster who demonstrates the most interest and aptitude in forecasting. Kershner (1967) found five tests that correlated well with forecasting skill; however, these tests were never used operationally to select weather forecaster candidates. There is little data either supporting or not supporting the contention that forecaster aptitude and interest are important. It is not known whether these characteristics are inherent in good forecasters or are brought out by good managers.

Weather Station Operations (Systematic Forecasting Procedures)

Improvement of station operations was addressed by Willett (1951), and has been discussed occasionally (Fulks, 1948; Snellman, 1975, Kaehn, 1978; German, 1979a; Schwartz, 1980 for example). Willett recognized that the abundance of analysis and forecasting tools produced during the 1940s sometimes had an adverse impact in weather station operations. Various forecasters or forecasting teams often used differing approaches and tools, resulting in poor continuity. Since the main forecasting method was extrapolation, the results could be disasterous. He advocated adoption of one set of analyses and procedures to be used by all forecasters, not only within a station but throughout a service. Standardization of weather forecasting activities has been advocated for at least 30 years. Little progress has been made except where manually produced forecaster aids have come to be produced by computer. Even then the role of the person in the forecasting process is handled differently nearly everywhere.

Forecasters build their forecasts subjectively using whatever is available and can be assimilated in the available time. While forecasting no weather is done correctly about 90 percent of the time, forecasting significant weather needs improvement. Much of the important weather is associated with structures which appear to be synoptically weak, but in reality may be strong in the mesoscale. Ways are needed to identify these structures and to forecast them. In addition improvement is needed in forecasting cloud formation, decay, and translation. Some of these problems could be mitigated with improved synoptic scale models, but most are likely to need a much finer scale approach. Today's mesoscale models may be a good approach, but are not likely to be of significant help within the next 10 years due to the state of the art and the impracticality of running them for every location. Thus, for the next few years at least, efforts to develop systematic approaches to forecasting will need considerable effort.

There are several programs working toward automation of large parts of station procedures (Naval Environmental Display Station (NEDS) - Thormeyer, 1978; Automation of Field Operations and Services (AFOS) - Klein, 1978; Prototype Regional Observation and Forecasting System (PROFS) - Beran and Little, 1978, and Automated Weather Display System (AWDS) - Best, 1977). In addition the roles of the man and the machine were discussed at the 1978 AMS Conference on Weather Forecasting and Analysis (Snellman and Murphy, 1978). Overall the consensus is that weather forecasting will improve with the implementation of these systems, but there are no studies with data illustrating that improvement will result from the actions now being implemented. None of these systems can run mesoscale models of sufficient sophistication to be helpful.

Another factor that often is mentioned as important is the station workload. Workload in weather stations has changed significantly. Thirty years ago most forecast offices were 24 hour stations and forecasters spent high percentages of their time in meteorological analysis, prognosis, and forecasting. Now most of these synoptic meteorological analysis and prognosis tasks are done in weather centrals. The time saved was intended to increase the time available for the forecaster to think through the meteorology to develop more accurate forecasts. Instead, forecasters have been assigned other duties such as briefing and coordinating. In addition many weather stations, especially military, are only open part time. The workload is added generally because of reductions in forces due to rapid rises of personnel costs, and because significant weather tends to occur relatively infrequently. In the predominantly, not-hazardous weather situations the forecaster is likely to be perceived as being able to handle additional tasks, with the result that management determines that fewer people are required and assigned. The development of devices to assist forecasters, such as Automation of Field Operations and Service, Automated Weather Distribution System, and Naval Environmental Display Station have not been heralded as having significant impacts on the long term trends noted. Overall, the amount of time forecasters have available to diagnose and forecast probably has not increased, and, except where forecasters have developed an attitude and interest to forecast well, there are indications that less and less thought now is being applied to forecasting.

Commercial Weather Services

So far discussion has concentrated on public and military weather services. What about commercial services? The growth of commercial weather services indicates that these services are perceived as being superior to the service routinely available from the National Weather Service public forecasts (Wallace, 1971 and Gifford, 1977). As an example of the rate of growth, there were 85 listings in the certified consultant and professional directories in the December 1979 issue of the Bulletin of the American Meteorological Society. Wallace (1971) reported there were 28 listings in the December 1960 issue. This represents an increase of about 200 percent in 20 years including firms that do not provide real time forecasting services. Forecast verification data for these enterprises were not found in the literature; however, Suchman, Auvine, and Hinton (1979) presented an evaluation of the benefits of meteorological services to the clients of one firm. Services to road and street departments, electric utilities, and gas utilities were discussed. In general, a single accurate forecast of a significant change more than pays for the costs of the services for one year. Similar statements have been made by Wallace (1971), Freese and Notis (1976), and in the Business Week Magazine (1979). Although it is clearly established that the major motivation for subscribing to a weather service is financial, a few other reasons were given. The importance of financial benefits as a reason for buying commercial weather service logically leads to strong motivation to produce accurate forecasts. Such direct strong motivation is not present in forecasting games and in forecasting facilities not directly interfacing with a user.

Forecaster Motivation

Forecaster motivation plays a major role in enabling the commercial weather services to successfully give the forecast accuracy and service that has supported growth in both number and size. Forecaster motivation has been a major factor in the good performance of the Air Weather Service forecasters, and it was a major factor in the improvement of the Western Region forecasts as reported by Snellman (1977) and MacDonald (1977). Effective motivation programs need management support in the form of helpful technical information, feedback of verification data, and consistent perception and recognition of exceptional meteorological work. Air Weather Service distributes publications and soundslide seminars tailored to forecasting personnel; most stations verify forecasts daily, and a centralized verification program is being prepared. We have found that the most important motivational factor is unit leadership. Occasionally an Air Weather Service unit will experience a change in leadership without any change in the forecasters. In some of these cases, an immediate and dramatic change in forecasting performance has occurred. Interviews with some of these leaders, and others who maintained good forecasting performance wherever assigned, revealed that the main common factor was effective motivation. As an example, one unit had the lowest performance of all AWS units in Europe. Within a few months after a new commander was assigned, this unit's performance rose to first place in the theater and remained there throughout the commander's tour. The key was the interest shown by the commander in the people and their work. We have found no other factor, including experience, meteorological education, forecasting aids, forecasting guidance, consultant visits, seminars and publications, as effective as the performance typically achieved by commanders who can inspire (motivate) the forecasters to perform well. Clearly, forecaster motivation is an important factor in forecasting performance and skill.

We can reasonably assume that management emphasis was not a major factor in the university games nor in the results reported by Charba and Klein (1980b). In the university games participation generally was voluntary and extracurricular. Both factors are consistent with the aura of freedom with personal responsibility fostered by universities. This does not mean that the individuals involved are inadequately motivated or treated the contest lightly. To the contrary, the author understands from a former student participant (W. F. Johnson, Lt Col, USAF), that the participation is serious and intense. Nevertheless, the motivation provided by a potentially bruised ego on a once a day product might not be as motivating as full time forecasting responsibilities for a demanding customer. The skill achieved was quite high; it is possible that the skill was too high to be affected by the improvements so far achieved by the numerical models. Thus it is possible that improvements will be achieved later with further improvements in large scale numerical models. Breakthroughs in mesoscale meteorology and methodology would also help. There has been little published concerning management emphasis of forecasting quality in the NWS, a fact which coupled with a few articles and comments to the contrary (Stover, 1974; Golden, et. al., 1978; Roberts, 1978; Schwartz, 1980) lead one to believe that improvements are possible through encouragement and motivation of forecasters. A note of caution; motivational programs can have unwanted side effects. We understand that the Western Region program was discontinued because of them, and Air Weather Service has had to adjust its program several times.

Discussion

The traditional approaches for improving weather forecasting were reviewed. Improvements in data, computers, and models which resulted in significant increases in forecasting skill for forecasts of some elements were not achieved across the board. Additional factors appear to be important. University meteorological education was not found to be essential to good forecasting performance. In fact, beyond fundamental concepts, no correlation was found between amount of university education and forecasting skill except for one study. This study was based on biographical characteristics of good and poor officer and enlisted forecasters as assessed by peers. The good forecasters in each group tended to have more university education. However, this study might not be representative of forecasting operations in the 1980 base weather station.

1980 base weather station. Overall, we conclude that university meteorological training is not required for day to day terminal forecasting. Chanute training is adequate, provided enough university trained meteorologists are available for training, consultation, and guidance.

Meteorological experience also did not seem to be an important factor after the first month or two. This assessment seems to apply both to overall forecasting experience and to on station experience. One study indicated that forecasters who began forecasting prior to age 25 were better. Recently many forecasters crosstrained into the weather career field; often the crosstrainees outperformed the others. There are, of course, some poorer performers in this group, but they seem to be in the minority. There were a few indications that experienced forecasters tend to forecast rare events more accurately. However, on closer inspection the instances of superior forecasting could be attributed to instation "education," meaning OJT, review of local case studies and other forecaster reference materials. We conclude, that forecasting experience beyond the initial one to two months, is not related to forecasting skill.

Forecaster aptitude and interest appear to be important. These attributes generally seem to be developed during various stages of forecasters careers. Positive managers seem to be helpful in this process. Another factor considered was weather station operations, especially the degree of systematization of analysis and forecasting procedures and the forecaster workload. In practice, development of systematic procedures has been slow. Progress has been made for those forecaster aids produced completely by machine. The interpretation of these aids is far from uniform; so there still is a great need for establishing systematic procedures. For example, some of the MOS forecasts still appear to have greater skill than manual forecasts even several years after this anomaly was first published. Forecaster workload doesn't appear to have decreased appreciably in spite of improvements in forecaster aids. Forecasters do not have more time to spend on thinking through forecasts, especially in poor weather. These two aspects of station operations both are desirable, but data showing they will provide an incremental increase of skill are lacking.

The final attribute examined was forecaster motivation. The rapid increase in number and size of private sector meteorological service companies was attributed primarily to the monetary incentive. Forecaster motivation in government meteorological services was found to be present in units with excellent performance. In addition, in case after case, stations that had long records of poor performance achieved dramatic improvement after assignment of a new officer in charge. Interviews with some of the successful leaders indicated simple techniques were used such as setting good forecasting as a unit goal, making activities directed toward this goal first priority, public recognition of successful individual and team efforts, and providing encouraging guidance when needed. It was suggested that forecaster motivation is the major one that determines whether the state of the practice of weather forecasting is comparable to the state of the science. Motivation was most effective when a mechanism was available to provide prompt feedback of forecasting skill, and a program established to make pertinent and useful technical information available. However, motivation can be counter productive if used without sufficient sensitivity to the needs of the individual forecasters. No other factor, attribute, or characteristic has been found which is more important to high forecasting skill than strong motivation of the forecasters by the person in charge.

CONCLUDING REMARKS

This investigation was begun with the expectation of finding that our overall weather forecasting performance had not improved recently, primarily because of low forecaster experience and significantly reduced formal meteorological education and training. Thus, it was surprising to reach the conclusion, on the basis of available data, that our forecasting performance had significantly improved in spite of decreased forecaster experience and education. The effects of experience and education apparently are realized in the first two to three months of active forecasting. This finding raises several questions which can only be answered through specifically directed research. Topics should include measuring the forecasting skill of highly versus minimally experienced and/or educated forecasters, validating the forecaster selection tests identified by Kershner (1967), and evaluating the effects of bonus pay for high performance, less forecaster workload, and inclusion of training time in manpower computations. Inferences made on these subjects based on data collected 30 years ago are of questionable validity because the background and characteristics of the typical AWS forecaster are so different today. Such studies would be useful to both civil and military organizations, and could be conducted by either.

The conclusion that forecaster motivation is the single most important factor determining forecaster skill was somewhat disappointing although not too surprising. We knew it was important because of our professional military education courses and experience. As meteorologists, we would have liked to find more sensitivity to the science of meteorology in the available skill measuring techniques. This subject also needs further research.

In general, the overall result of this effort was a revalidation of the cost effectiveness of Air Weather Service emphasis on a forecaster force mostly composed of enlisted personnel. It indicates that corporately we may be overly concerned with forecasting experience and formal training, and insufficiently concerned with forecasting motivation, forecaster selection, and enhancing the thought processes required for forecasting. The AWS emphasis on forecasting skill apparently was effective, and should be continued. Numerical weather prediction efforts should continue, and are likely to improve weather forecasting over the next few years. Further improvements likely will be achieved through continued emphasis on weather forecasting skill and on effective programs to encourage forecasters to routinely do the hard mental work with basic meteorology that is essential for good weather forecasting.

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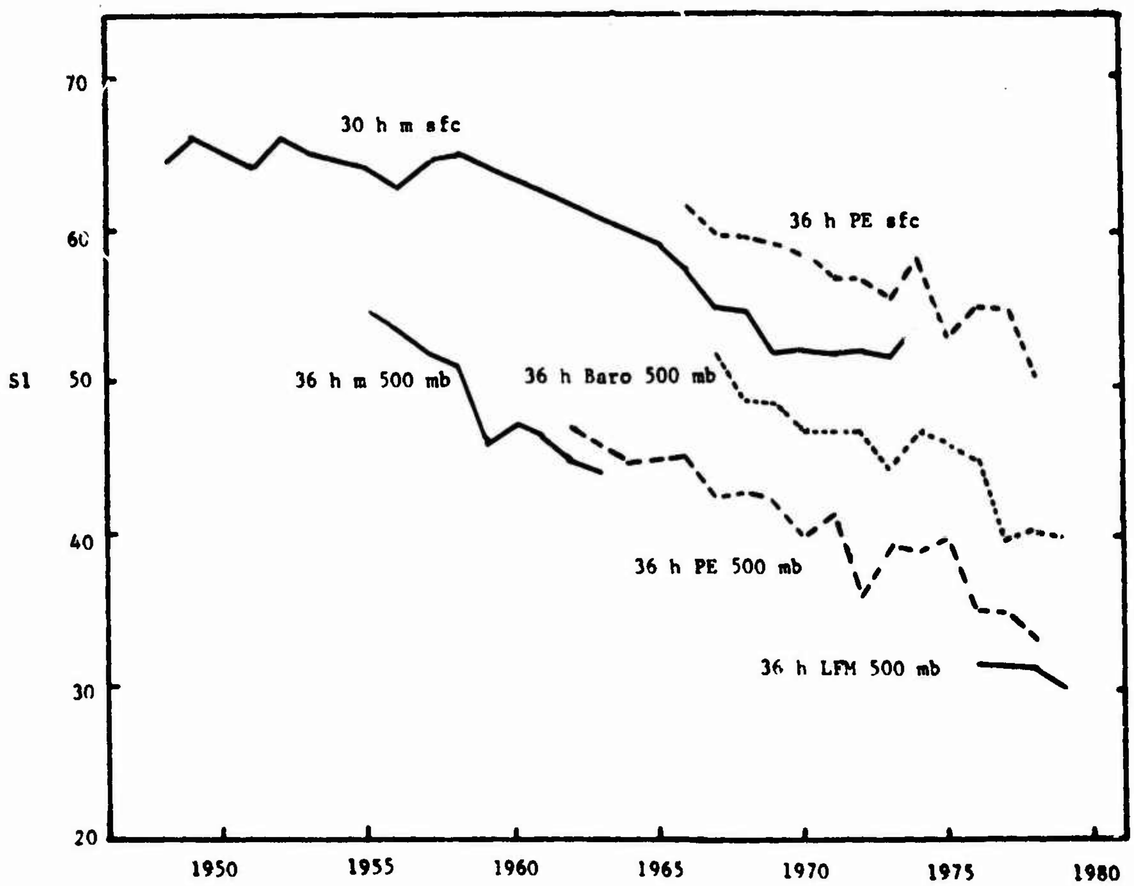


Figure 1. 30 hour surface and 36 hour 500 mb forecasts SI score. (Fawcett, 1977, updated from NMC verification data.)

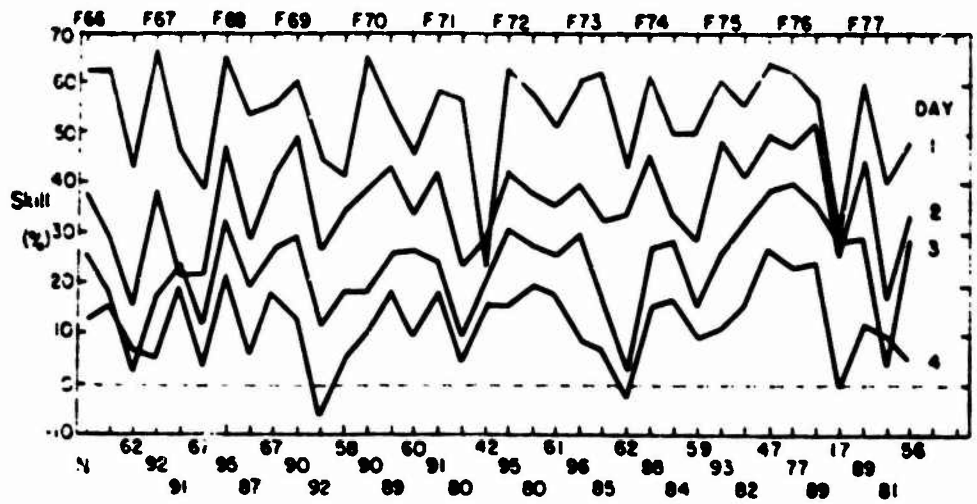


Figure 2. Minimum temperature forecasts, MIT consensus skill. Percent improvement over climatology, first (1) through fourth (4) 24 hour periods (Sanders, 1979).

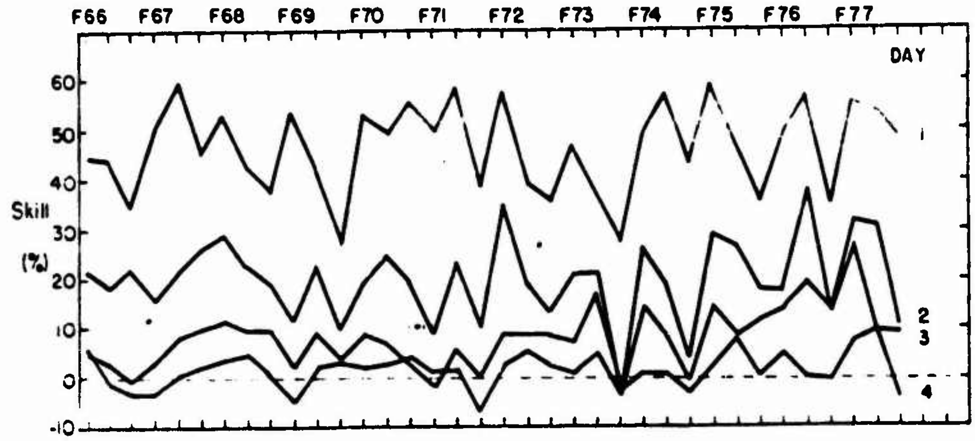


Figure 3. *Probability of six classes of precipitation amount, MIT consensus skill: none, trace, 0.01 - 0.04 in, 0.05 - 0.15 in, 0.16 - 0.45 in, > 0.45 in (Sanders, 1979).*

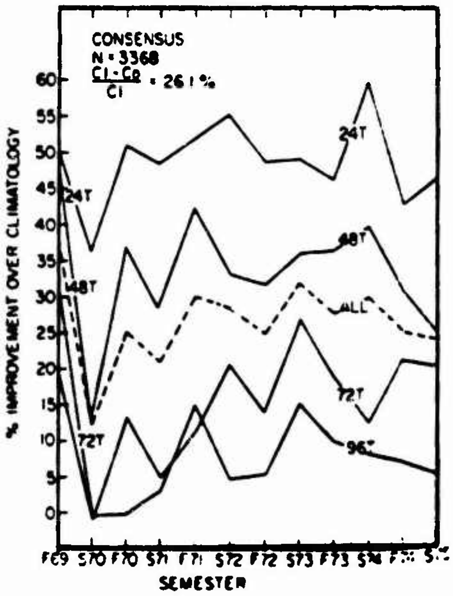


Figure 4. *Temperature forecasts, SUNYA percent improvement of consensus over climatology, 24 to 96 hours (Bosart, 1975).*

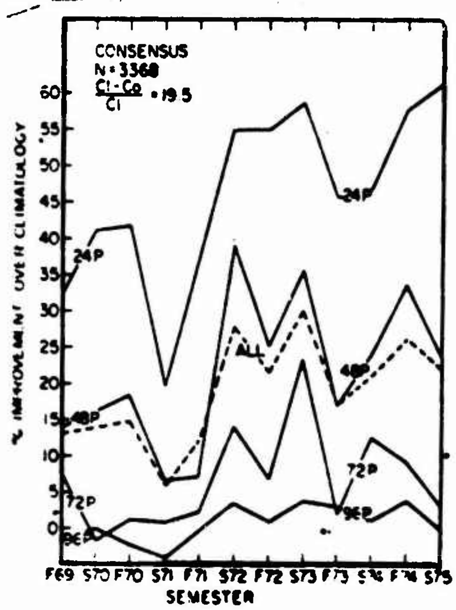


Figure 5. *Same as Figure 4, except for precipitation (Bosart, 1975).*

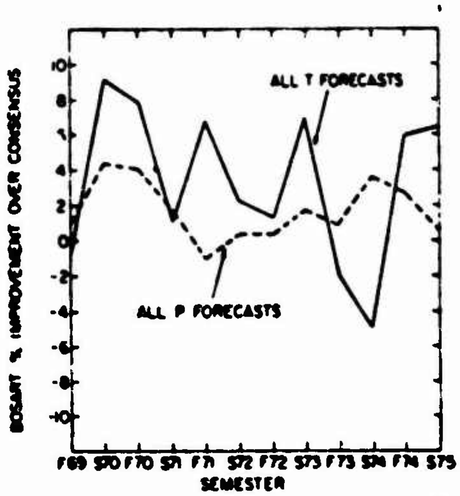
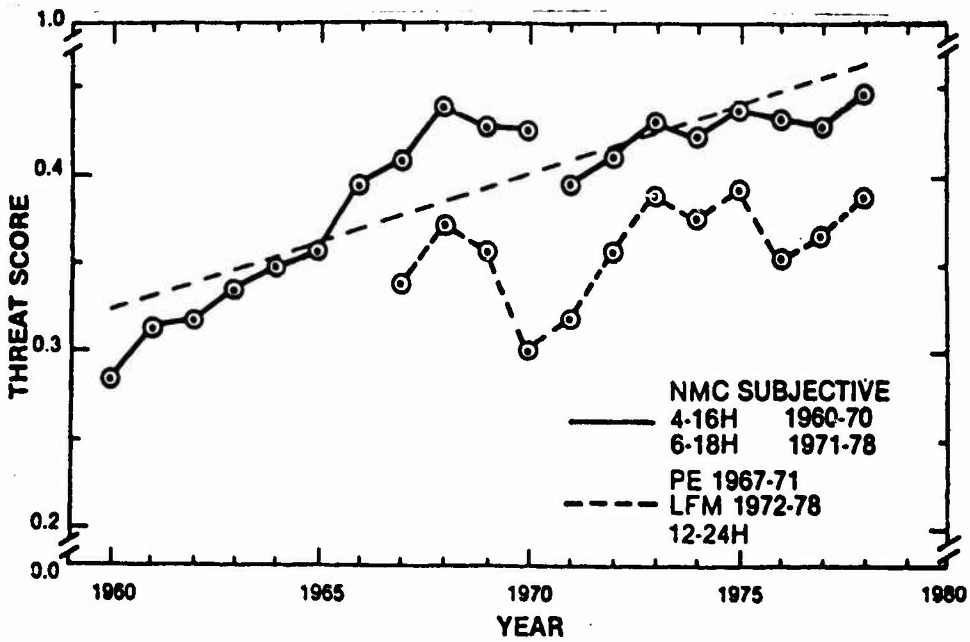


Figure 6. Percentage improvement over SUNYA consensus temperature (T) and precipitation (P) forecasts by Dr. Bosart (Bosart, 1975).



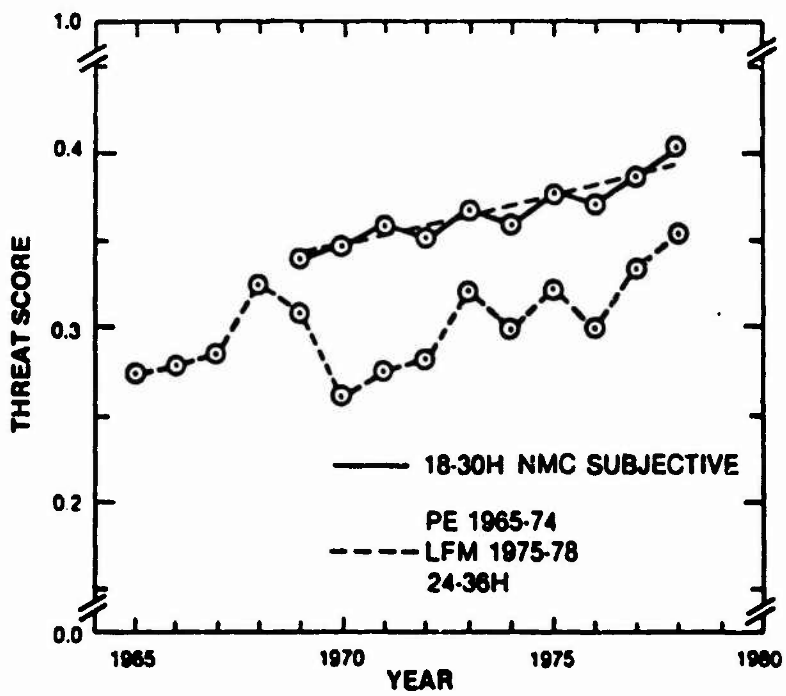


Figure 7. Categorical forecasts of measureable precipitation, NMC subjective and objective threat score (Charba and Klein, 1980a).

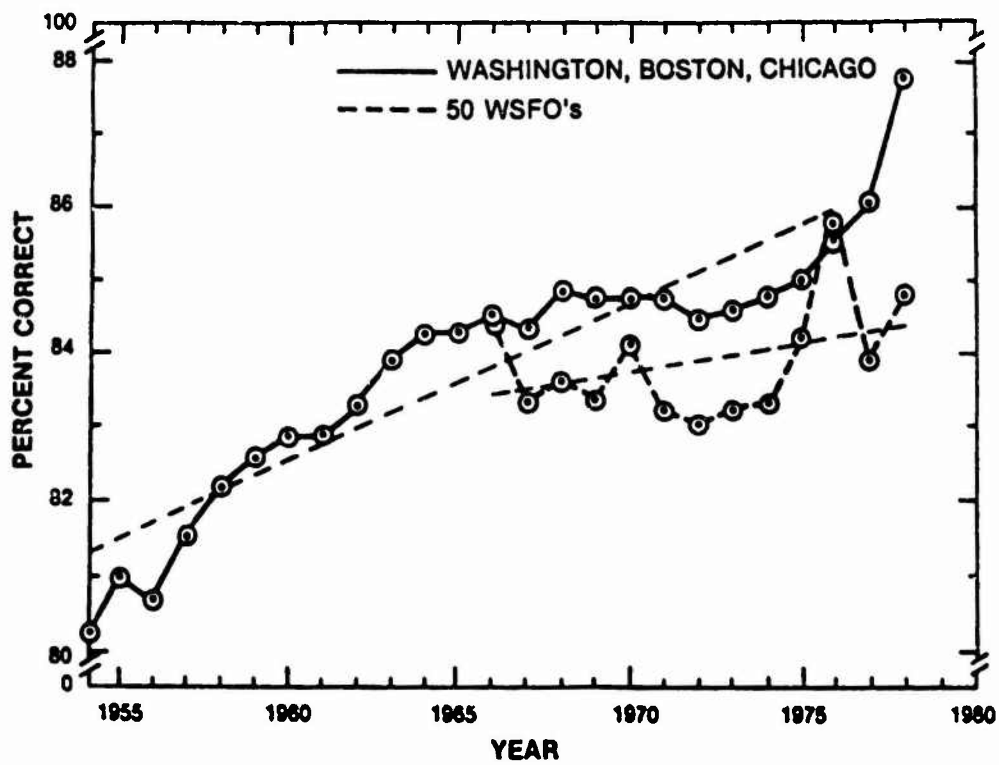


Figure 8. Categorical forecasts of measureable precipitation, local forecasters percent correct (Charba and Klein, 1980a).

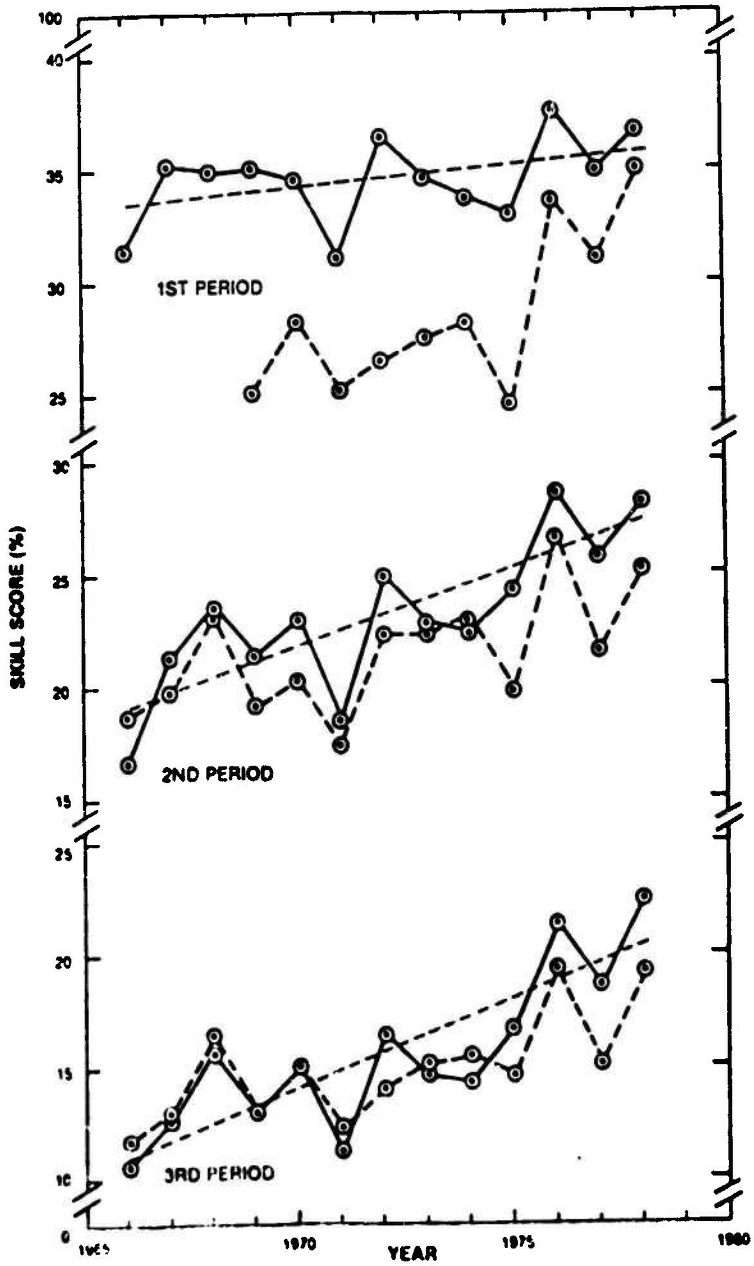


Figure 9. Probability of measureable precipitation, local (solid) vs automated (dashed), skill score. Local forecasts (solid line) are valid 3 - 15 hours, 15 - 27 hours, and 27 - 39 hours after issuance, respectively. These forecasts are issued about 9 hours after 0000 and 1200 GMT; the objective forecasts (dashed line) are issued about four hours earlier (Charba and Klein, 1980a).

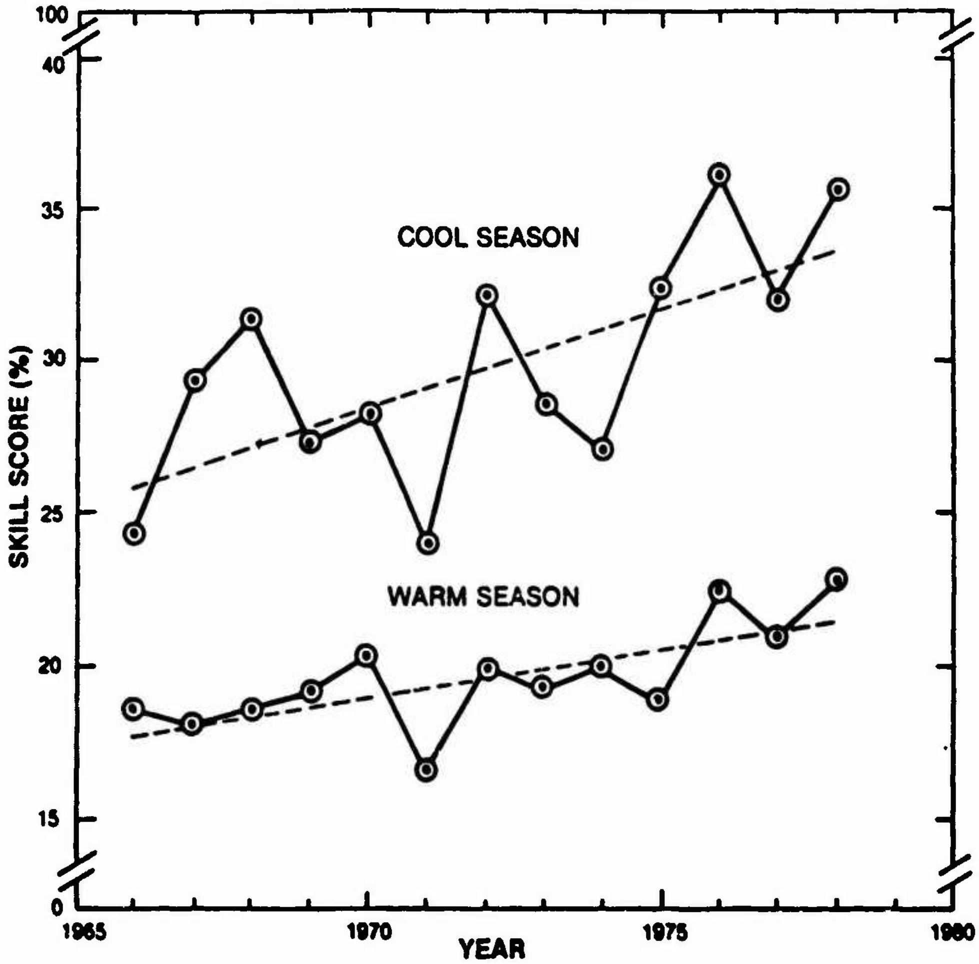


Figure 10. Probability of measureable precipitation, cool season vs warm season (Charba and Klein, 1980a).

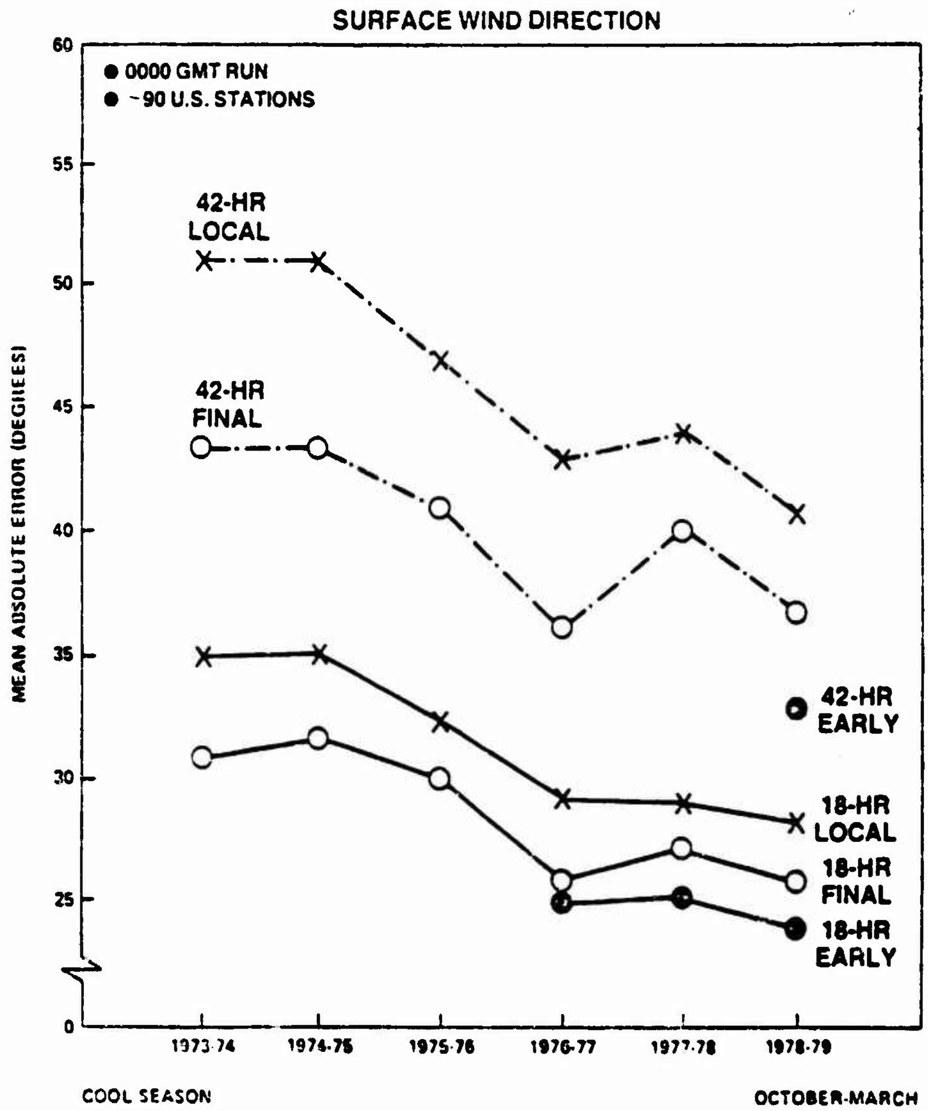


Figure 11. Surface wind direction, NWS mean absolute error, local and objective (MOS early and final), cool season, 00Z cycle. (Hebenstreit, et al., 1979).

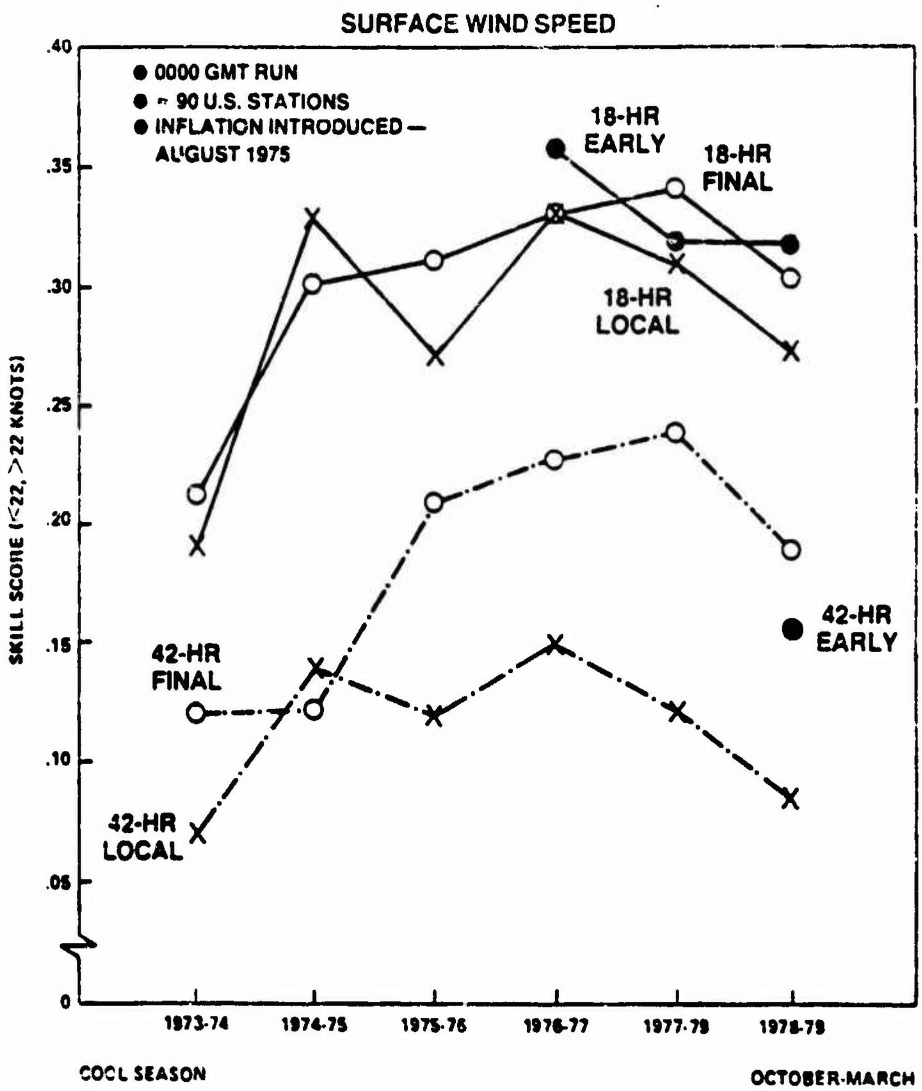


Figure 12. Surface wind speed, LTE 22 or GT 22 kts, NWS skill score, local and objective (MOS earlier and final), cool season, 00Z cycle. (Hebenstreit, et al., 1979).

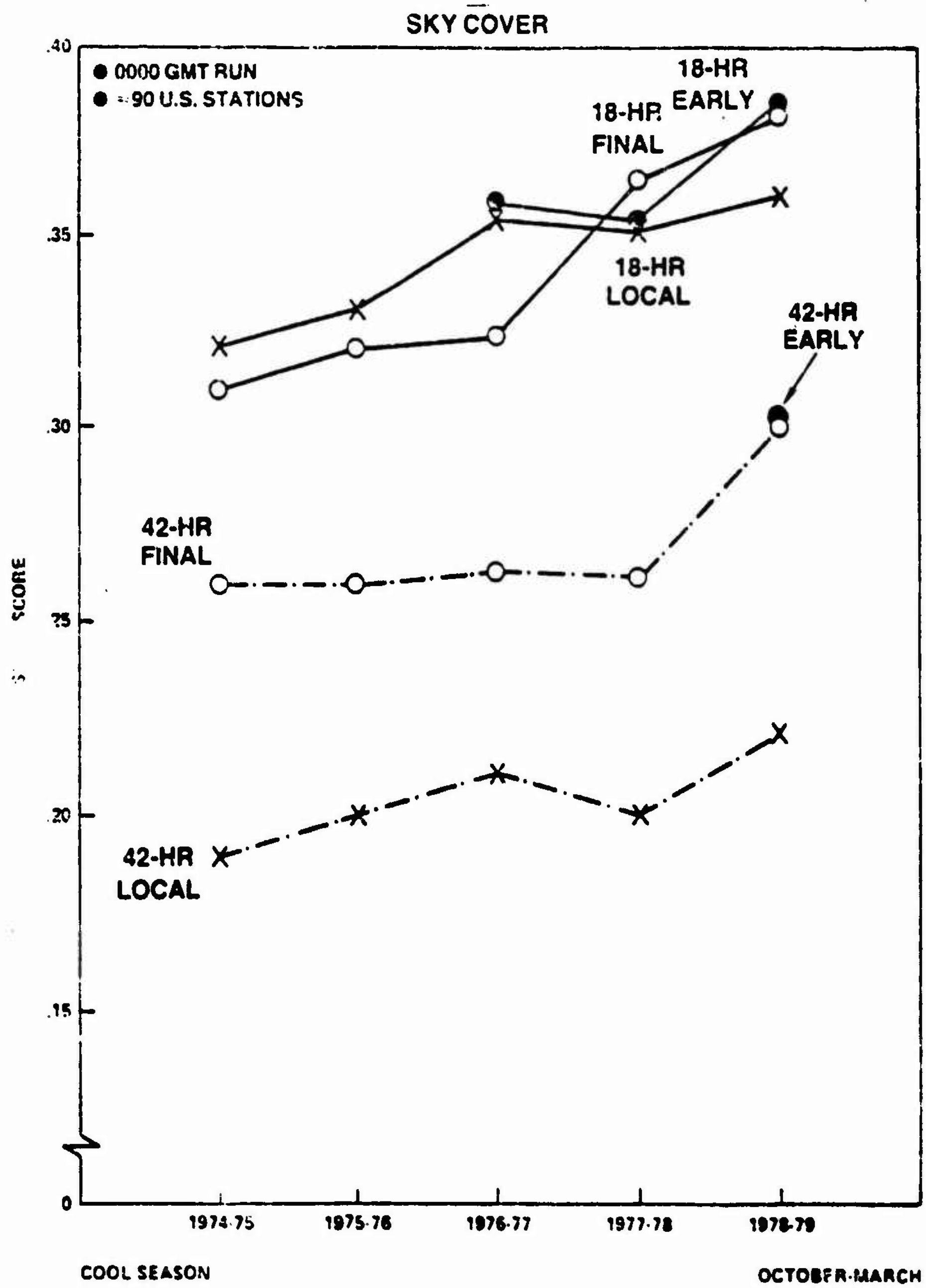


Figure .3. Sky cover, NWS skill score, local and objective (MOS early and final), cool season, 00Z cycle. (Hebenstreit, et al., 1979).

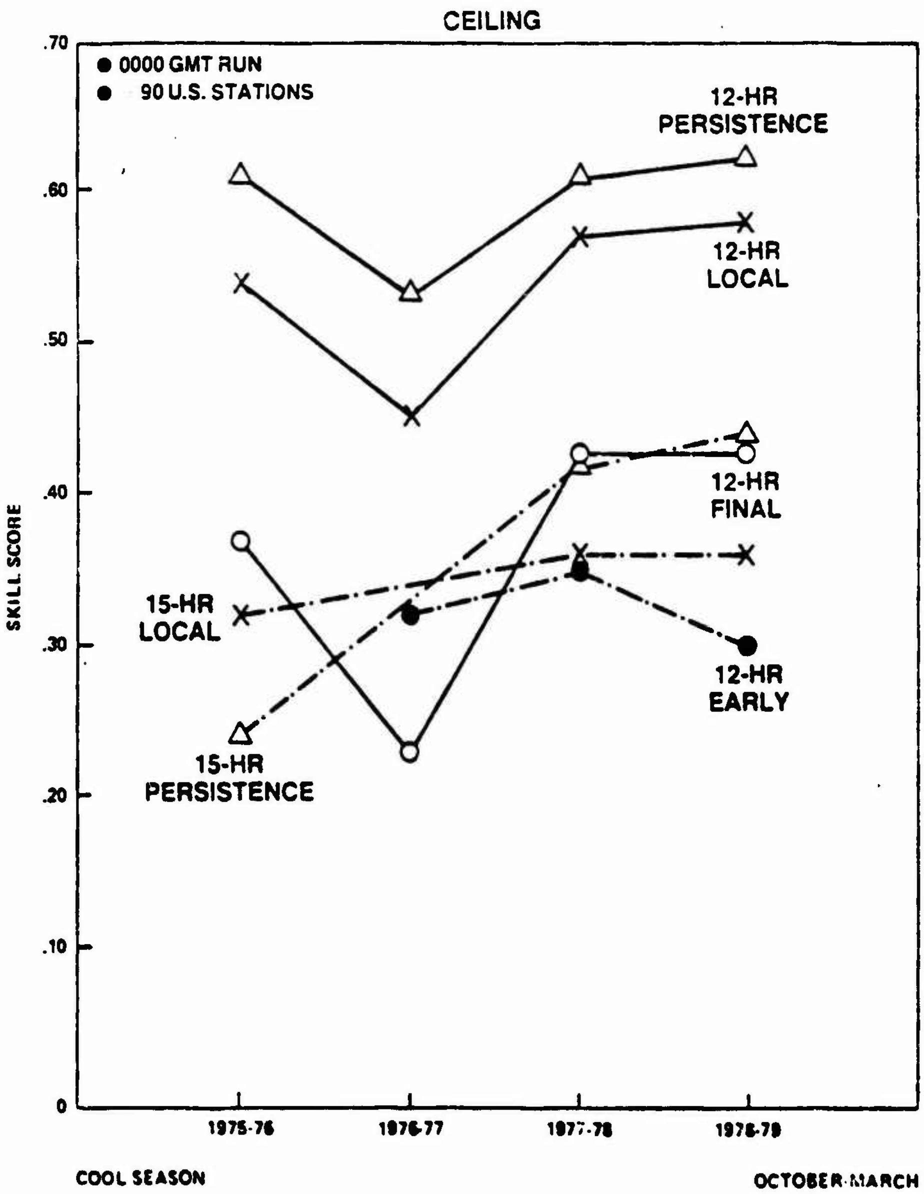


Figure 14. Ceiling, NWS skill score, local, persistence, and objective (MOS early and final), cool season, 00Z cycle. These forecasts are for various projections - the early and final objective forecasts use the 03Z and 06Z observations respectively; the persistence and local forecasts use data through 09Z and 10Z respectively (Hebenstreit, et al., 1979).

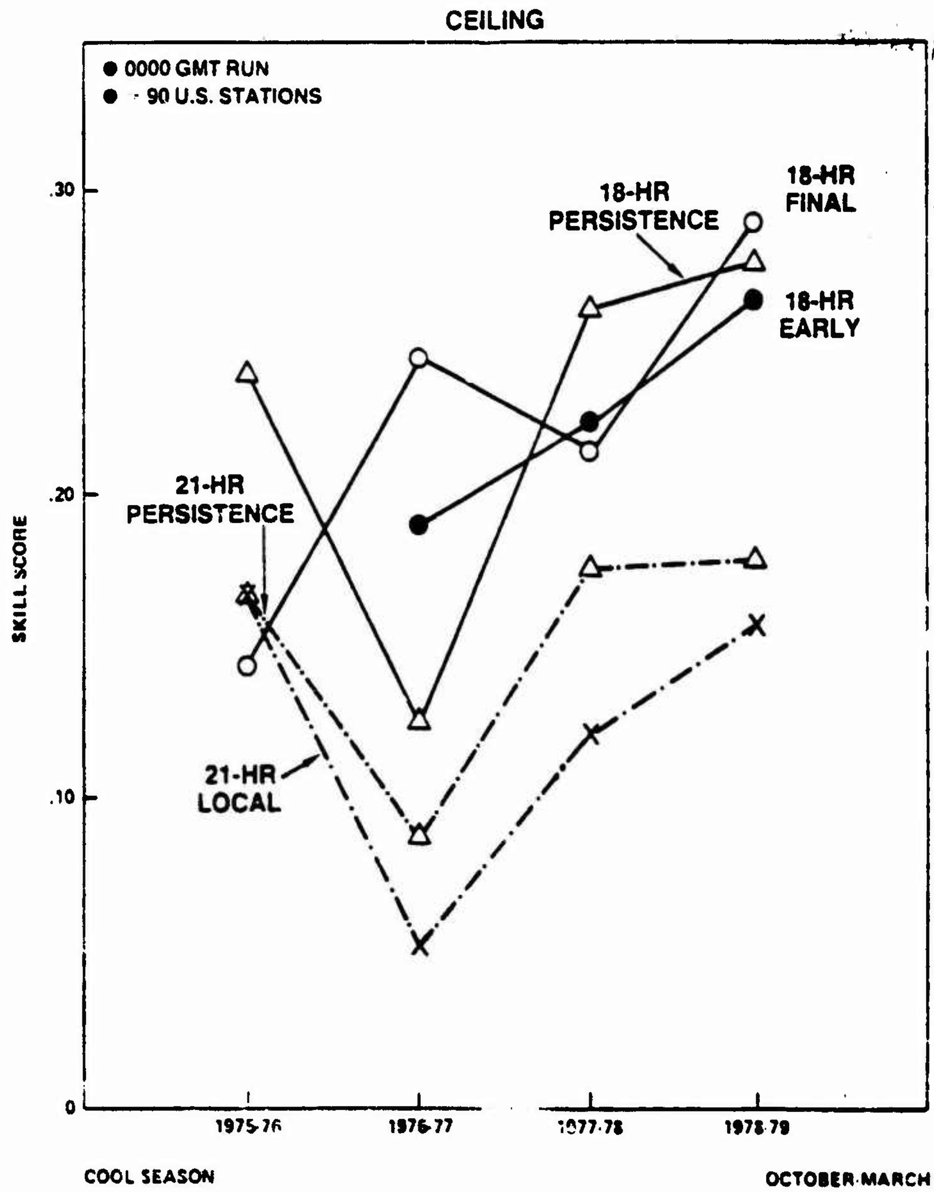


Figure 15. Same as Figure 14 for 18 - 21 hours (Hebenstreit, et al., 1979).

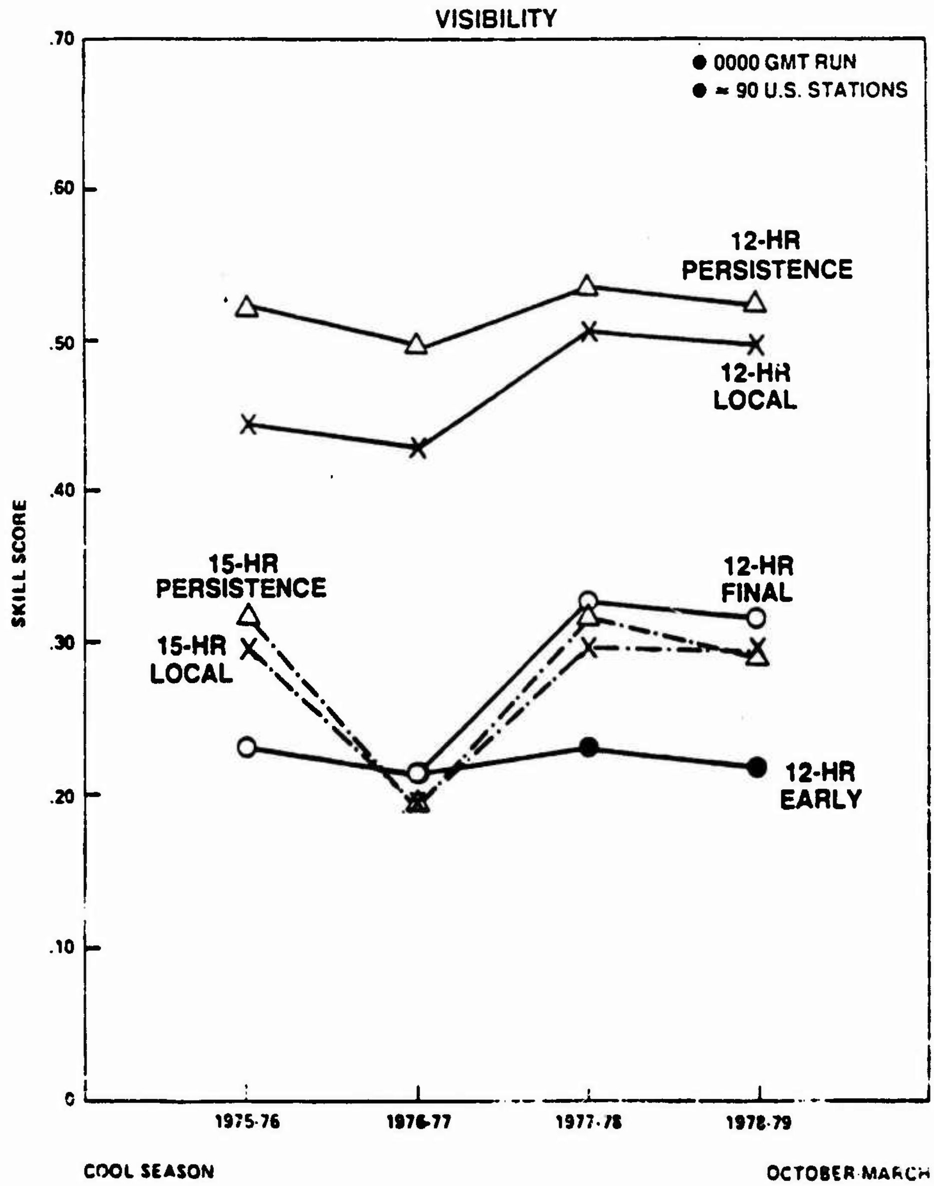


Figure 16. Same as Figure 14 for visibility (Hebenstreit, et al., 1979).

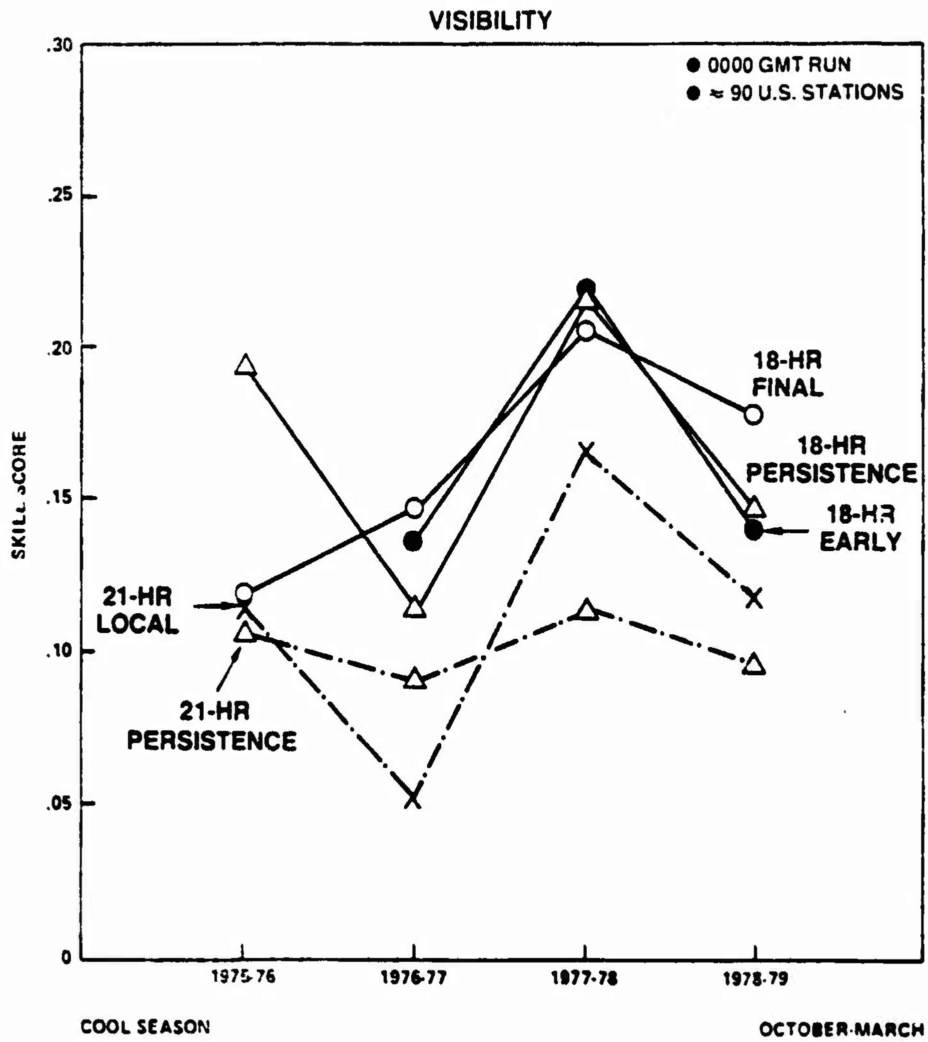


Figure 17. Same as Figure 15 for visibility (Hebenstreit, et.al., 1979).

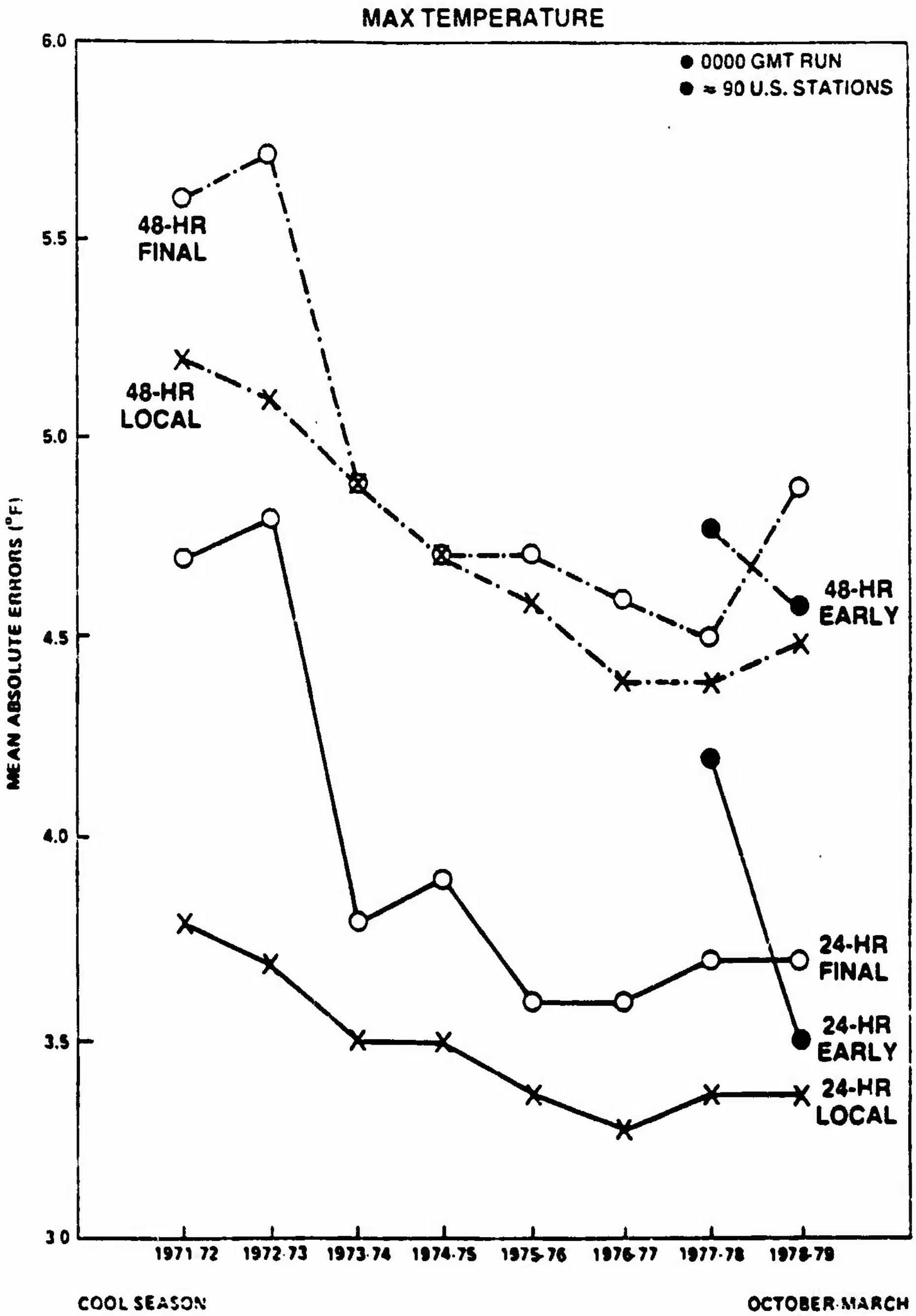


Figure 18. Maximum temperature, NWS mean absolute error, local and objective (MOS early and final), cool season, 00Z cycle. (Hebenstreit, et al., 1979).

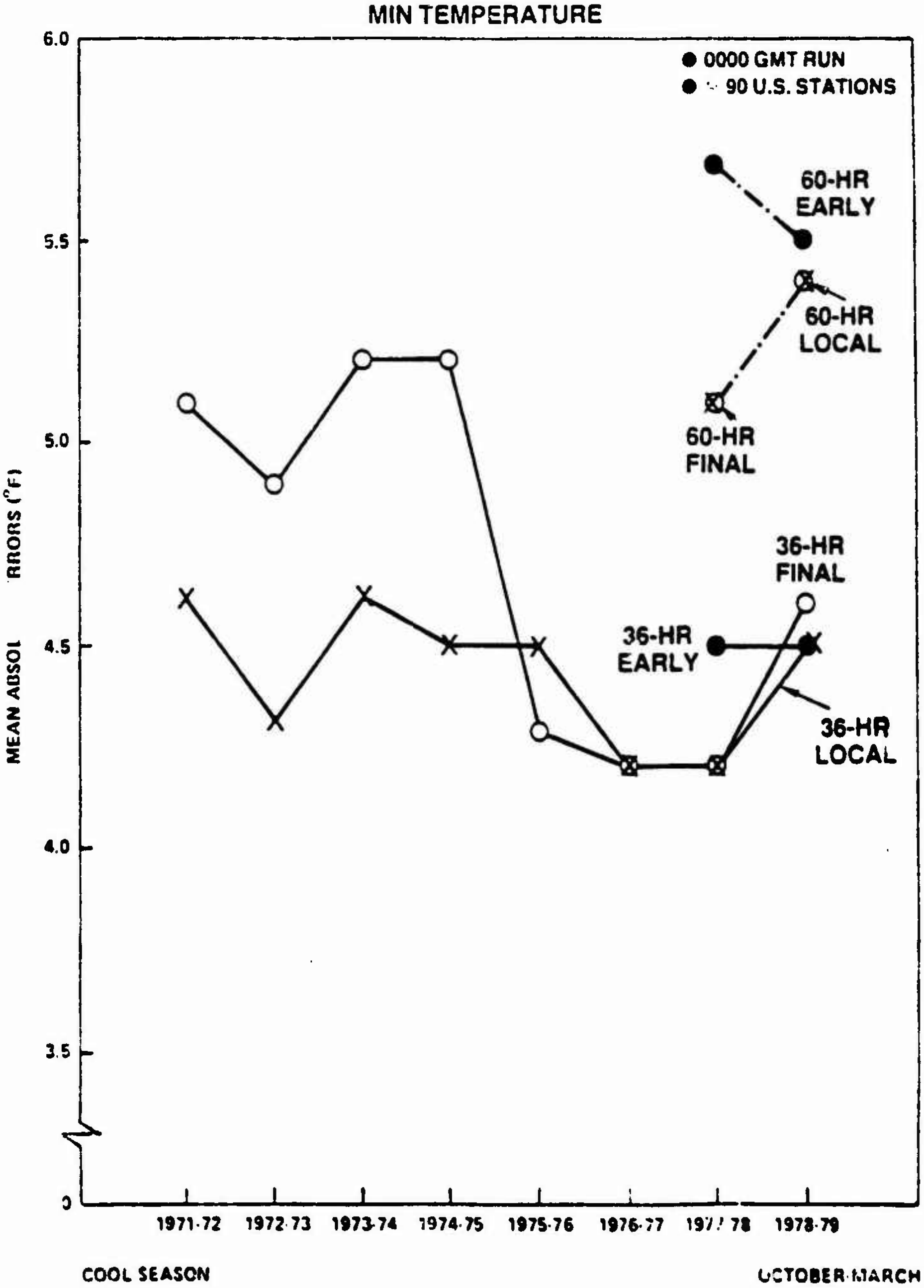


Figure 19. Same as Figure 18 for minimum temperature (Hebenstreit, et al., 1979).

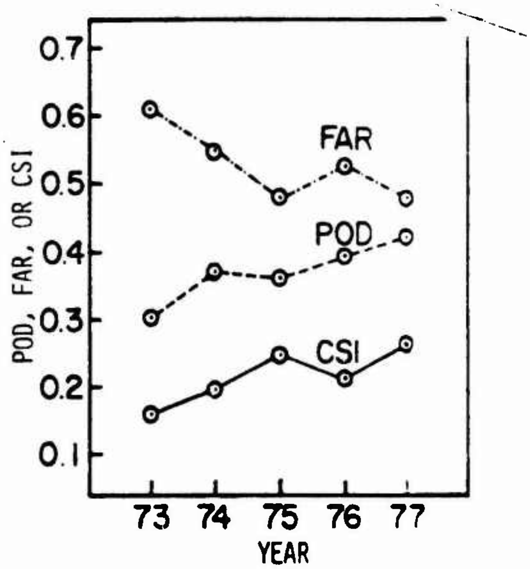


Figure 20. NWS severe weather outlook false alarm rate (FAR), probability of detection (POD), and critical success index (CSI). (Pearson and Weiss, 1979)

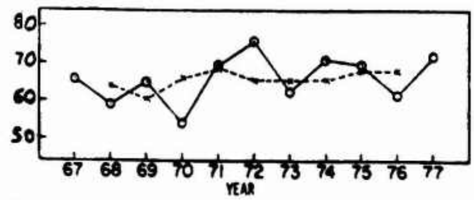


Figure 21. NWS tornado watch percent correct major tornado outbreaks and three year running average (crosses). (Pearson and Weiss, 1979)

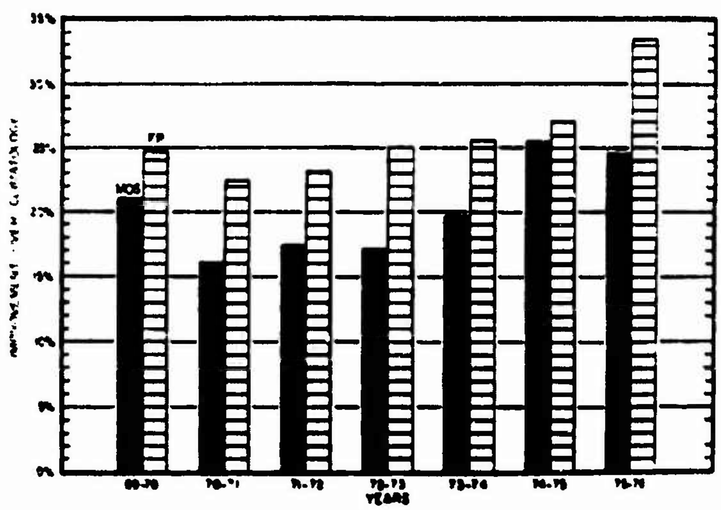


Figure 22. Probability of precipitation, NWS Western Region field forecaster (FP) vs MOS, percent improvement over climatology, December through March, all forecast periods. (Snellman, 1977).

ESTERN REGION SUMMARY   PERIOD: 1976

F7 CEILING

OBSERVED \ FORECAST	1	2	3	4	5	TOTAL
1	99	86	19	4	46	254
2	57	138	85	46	138	454
3	0	52	154	101	269	656
4	1	29	70	521	675	1334
5	61	104	176	712	24065	25138
TOTAL	226	489	512	1464	25193	27884
BIAS	.89	1.05	.77	1.12	1.00	

PER CENT CORRECT: 89.57

SCORE: 67.30

IMPROVEMENT OVER MOS (PER CENT): 1.05

MOS CEILING

OBSERVED \ FORECAST	1	2	3	4	5	TOTAL
1	59	29	4	0	155	254
2	27	67	25	42	323	444
3	4	21	45	137	455	664
4	2	10	49	290	937	1294
5	34	61	82	511	24530	25190
TOTAL	125	150	205	996	26400	27884
BIAS	.49	.34	.31	.76	1.05	

PER CENT CORRECT: 88.50

SCORE: 65.60

F7 VISIBILITY

OBSERVED \ FORECAST	1	2	3	4	5	TOTAL
1	229	59	63	39	91	481
2	31	30	47	35	84	227
3	53	53	151	183	260	730
4	27	21	76	294	431	849
5	66	80	180	550	24750	25836
TOTAL	406	243	517	1109	25598	27871
BIAS	.84	1.17	.74	1.31	1.01	

PER CENT CORRECT: 91.33

SCORE: 67.65

IMPROVEMENT OVER MOS (PER CENT): .79

MOS VISIBILITY

OBSERVED \ FORECAST	1	2	3	4	5	TOTAL
1	99	46	47	52	237	481
2	10	8	24	28	137	207
3	26	19	83	162	413	733
4	8	7	33	163	638	849
5	18	25	111	287	25195	25636
TOTAL	159	105	295	892	26520	27871
BIAS	.33	.51	.42	.82	1.04	

PER CENT CORRECT: 91.65

SCORE: 67.13

Figure 23. Ceiling and visibility contingency tables, Western Region forecaster and MOS, Mar - Dec, 1976. Categories: 1 = ≤ 100 ft: ≤ 3/8 mi; 2 = 200 - 400 ft: 1/2 - 7/8 mi; 3 = 500 - 900 ft: 1 - 2 1/2 mi; 4 = 1000 - 1900 ft: 3 - 4 mi; 5 = ≥ 2000 ft: ≥ 5 mi. (Snellman, 1977)

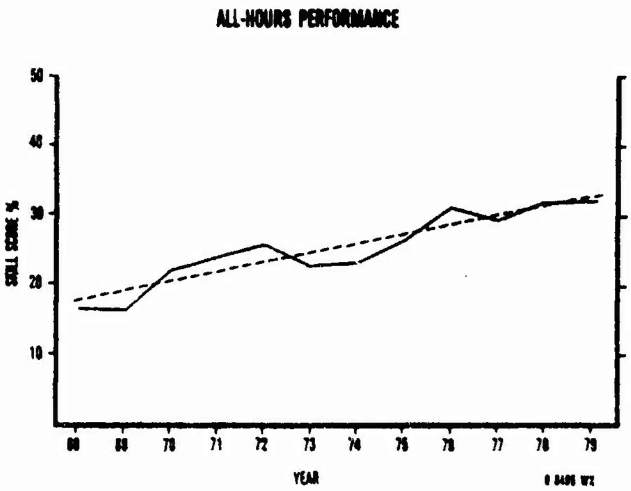


Figure 24. Ceiling/visibility, AWS all hours, percent improvement over persistence (German and Hicks, 1980).

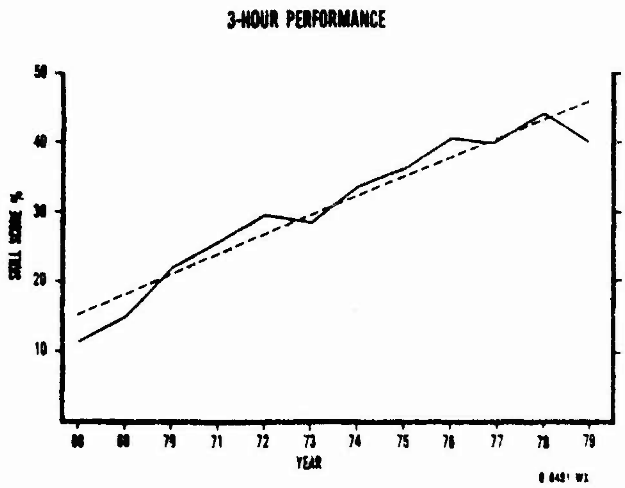


Figure 25. Same as Figure 24 for 3 hours only (German and Hicks, 1980).

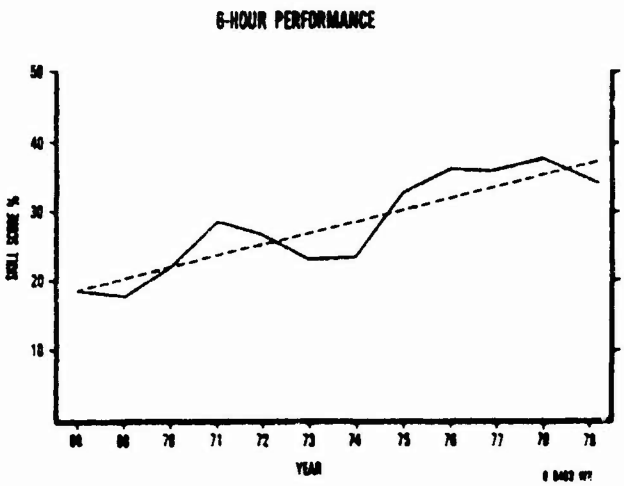


Figure 26. Same as Figure 24 for 6 hours only (German and Hicks, 1980).

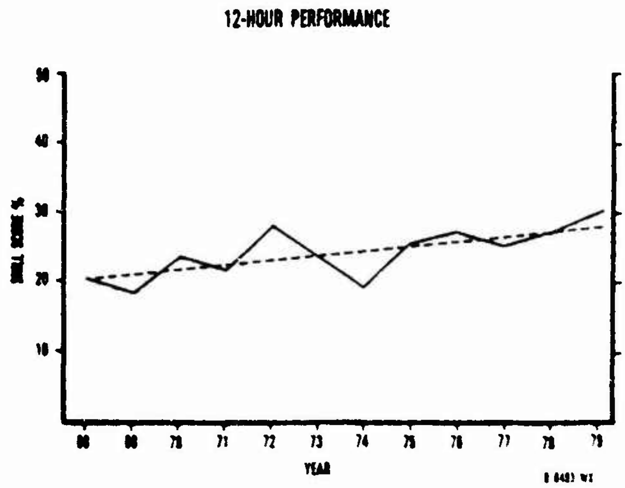


Figure 27. Same as Figure 24 for 12 hours only (German and Hicks, 1980).

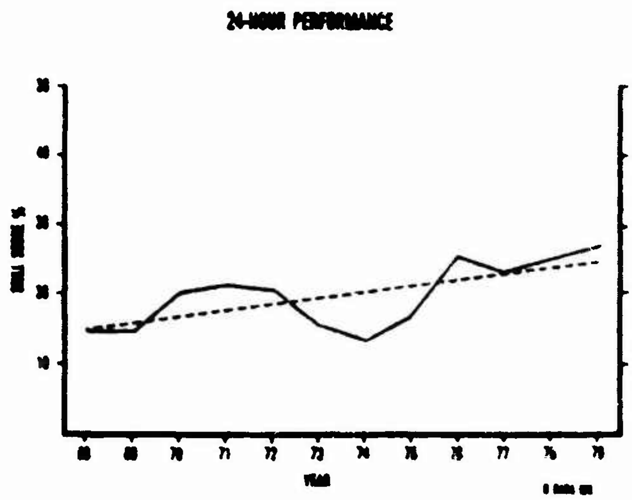


Figure 28. Same as Figure 24 for 24 hours only (German and Hicks, 1980).